Potential Air Contaminants and Noise Levels Generated by the Kodak NexPress 2500 Digital Production Color Press: A Study of its Emissions of Respirable Dust, Ultrafine Particulates, Volatile Organic Compounds, Ozone, and Occupational Noise Exposure

by Federico Leal

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In Loving Memory of
Agustina Arrieta Leal
(1924-2006)

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Abstract

The printing industry is beginning to get acquainted with the environmental impact of digital printing technologies. This study addressed issues related to the electrophotographic dry toner printing technology used in the Kodak NexPress 2500 Digital Production Color Press. The importance of these topics will grow as high-speed variable data printing becomes pervasive, because these printed products will become widespread, and a greater number of operators will be exposed to these technologies.

Indoor air quality and noise levels generated by the NexPress under normal operating conditions were studied: ventilation, dust, volatile organic compounds, ozone, and noise. The results of this study were then compared to a previous study that examined the environmental impacts of HP Indigo 3000 versus the Heidelberg Speedmaster 74.

All the test results were below the permissible exposure limits of the Occupational Safety and Health Administration. The NexPress proved environmentally friendlier than the HP Indigo 3000 and the Heidelberg Speedmaster 74 in all aspects under scrutiny except for average noise exposure. The results also show that the NexPress emitted similar gas, aerosol, and noise levels regardless of print run length.

This study highlights the need to develop regulations for ultrafine particulates, demonstrates how to compare environmental aspects between asymmetric printing platforms, and delivers a methodology to conduct indoor air quality and noise tests in a prominent branch of the digital printing industry.

Chapter 1

Introduction

This study is a combination of indoor air quality measurements with a noise level survey around the NexPress 2500 digital printer while it was running under normal operating conditions. The following parameters were measured: carbon dioxide levels, temperature, relative humidity, respirable dust, ultrafine particulates, total dust, volatile organic compounds, ozone, peak noise, and time-weighed average noise.

Topic Statement

Printers cannot easily replace expensive presses overnight just because the government determines that they are using harmful chemicals. Therefore, managers of printing companies must stay one step ahead of the regulators. The problem is that some printing processes are newer than others. As a consequence, there are processes whose environmental impact is better documented than others -digital printing is one such case of little publicly available information. Since it is closely tied to ever-evolving computer hardware and software, and because not all applications are well suited to this technology, the printing industry is beginning to understand the environmental impact of this process. This study was an effort to address some of these environmental issues as

they manifest themselves in the dry ink electrophotographic printing technology used in the Kodak NexPress 2500 Digital Production Color Press.

Significance of the Topic

Awareness of environmental and occupational exposure issues plays an important role in the selection of environmentally friendly technology. This topic was worthy of scholarly study because literature dealing with the environmental footprint of digital printing technologies is scant.

Digital printing devices have the potential to release dust, volatile organic compounds, and ozone during their operation. These emissions must be kept as low as possible in order to maintain good indoor air quality conditions and to protect the health of building occupants and employees (Gullison, 2006). Occupational noise exposure is another issue that all industries must address under the watchful eye of the U.S. Occupational Health and Safety Administration (OSHA), through the application of engineering controls and hearing conservation programs, if necessary.

Reasons for Interest

This topic first caught the author's attention when Dr. Mary Anne Evans gave a lecture in the Materials and Processes II course, which is part of the Masters in Print Media curriculum at RIT. Dr. Evans explained that there is very little information publicly available on the environmental impact of digital printing, when compared to all

the information that is available for lithographic printing. She also stated that printers rarely try to ascertain the impact that their technologies have on the environment.

In 10 or 20 years, the author will run his family's printing business in Costa Rica. There is a limited market for books, magazines, and other products that are printed conventionally in this small country. Therefore, in time, the company will have to expand into variable-data digital printing. The author chose the Kodak NexPress 2500 over the HP Indigo 3000 because the Kadam study (2004), which Dr. Evans referred to, had already analyzed that particular technology.

Glossary of Frequently Used Terms

Table 1 is a glossary of terms that will be used frequently throughout this document.

Table 1: Glossary of Frequently Used Terms

Term	Definition in the Context of This Study
Conventional Printing	Also known as "static printing". This term refers to traditional ink-on-paper approaches (offset lithography being the most common) where every sheet is reproduced from the same image carrier fixed with the same image (Romano, 2001).
Decibel (dB)	Unit of measurement of sound level; one tenth of a Bel (B) (OSHA, 2007).
Dry Toner	The marking material that the NexPress uses. It is made up of a polymer binder, a negative charge agent, and a colorant; it develops the latent image and it is transferred onto the paper (NexPress Solutions LLC, 2006).

Table 1 (continued): Glossary of Frequently Used Terms

Term	Definition in the Context of This Study
EHS Aspect	An element of an organization's activities, products, or services that can interact with the environment, health, or safety of the employees (Envirowise, 2006).
Electrophotography	A printing or copying method that uses an electrical charge to create an image on a photoconductive surface. Toner is attracted to the charged area, then transferred and fused to the paper (Romano, 2001).
Long Run	An entire printing press operation cycle that requires a relatively long time for completion due to heavy print load (Kadam, 2004). In this study, two hours or more was considered a long run.
Particulates	Solid or liquid matter suspended in the air, including nontoxic materials such as soot, dust, and dirt, and toxic materials such as lead, asbestos, suspended sulfates, and nitrates (Aerias, 2006).
PEL	Permissible exposure limit; a legal limit established for exposure of an employee to a substance (OSHA, 2007).
Respirable Dust	Dust that is capable of reaching and penetrating the gas exchange region of the human lungs (Aerias, 2006).
Short Run	An entire press operation cycle that requires a relatively short time for its completion (Kadam, 2004). In this study, it was understood as 30 minutes or less.
TLV	Threshold limit value; it represents conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse health effects (ACGIH, 2007).
Ultrafine Particulates	Particulates smaller than 2.5 micrometers in diameter (U.S. Environmental Protection Agency, 2007).
Volatile Organic Compound (VOC)	Any organic compound that participates in atmospheric photochemical reactions except those specifically excluded (U.S. Environmental Protection Agency, 2007).

Chapter 2

Applicable Mathematical Models

Of the five environmental aspects under scrutiny, as they are treated in this study, only noise exposure analysis requires understanding of specialized mathematical models. When calculating the combined noise detected by more than one dosimeter, the methods used by industrial hygienists are not intuitive; therefore, they are explained in this section.

The human sense of hearing responds to sound stimuli in a logarithmic manner (J. Schneider, personal communication, 2007). Logarithmic scales are useful when the data covers a large range of values, as is the case with the hearing sense. A logarithmic response helps compress this wide range so that our response to variations in weak sounds is similar to that in loud sounds (Robertson, 2007).

Logarithmic scales do not operate the same way as linear scales. For example, the combined noise emitted by two identical and constant 70 decibel (dB) sources is not 140 dB, but is instead 73 dB. In order to make such calculations, industrial hygienists use one of two methods: the Rule of Thumb Method, and the Calculation Method, as explained by Stewart (1999) and Berger (1986) respectively. The Rule of Thumb Method is preferable when five or less dosimeters are involved, and it is favored by the American Conference of Governmental Industrial Hygienists (ACGIH). The Calculation Method is

used by OSHA in all cases, and it is preferable if more than five dosimeters are involved (J. Schneider, personal communication, 2007).

Consider the average noise levels detected by five different dosimeters arranged in ascending order: 68.25, 68.58, 70.48, 70.68, and 71.97 dB. After arranging them in this manner, the Rule of Thumb Method can be used to calculate their combined noise effect. The principles involved in this method are seen in Table 2.

Table 2: The Principles of the Rule of Thumb Method

Difference in Decibels Between Consecutive Levels Arranged in Ascending Order	Number of Decibels to be Added to the Higher Level
$0 < \Delta < 1$	+ 3 dB
$2 < \Delta < 4$	+ 2 dB
$5 < \Delta < 9$	+ 1 dB
$\Delta > 10$	No Addition

If the difference between the first two dosimeters ($\Delta = 68.58 - 68.25 = 0.33$) is less than one, then according to Table 2, the combined noise effect will be the higher of the two levels plus three decibels (see the first row of Table 2). This new value (68.58 + 3 = 71.58 dB) is then compared to the following level (70.48 dB) using the rules of Table 2, and the process is repeated until there are no more dosimeters to compare.

The Rule of Thumb Method is explained step by step in Table 3. The average noise detected by the five dosimeters appears in *italic font*, and their (single) combined effect according to the Rule of Thumb Method is shown in **bold font**.

Table 3: Sample Application of the Rule of Thumb Method

Step	Addition of Averages in Incremental Order	Rationale According to Table 2
1	*68.25 dB* + *68.58 dB* = 71.58 dB	$\Delta = 0.3 \Rightarrow$ Higher of the two + 3 dB
2	71.58 dB + *70.48 dB* = 74.58 dB	$\Delta = 1.1 \Rightarrow$ Higher of the two + 3 dB
3	74.58 dB + *70.68 dB* = 76.58 dB	$\Delta = 3.9 \Rightarrow$ Higher of the two + 2 dB
4	76.58 dB + *71.97 dB* = **77.58 dB**	$\Delta = 4.6 \Rightarrow$ Higher of the two + 1 dB

If the difference between any two sources falls between the ranges specified in Table 2, for example if $\Delta = 1.50$ dB, then industrial hygienists must use their own discretion in order to proceed. Decisions such as this are made in Step 2 and Step 4 of Table 3, and the author's logic was to err on the side of caution by adding more decibels (rather than less) to the calculation. This is the reason why this method is not as accurate as the Calculation Method, in which no subjective decisions are involved.

The second method used by industrial hygienists to calculate the combined sound pressure level (SPL) detected by multiple dosimeters is the Calculation Method, and it involves the formula seen in Equation 1.

$$SPL_f = 10\log\left(\sum_{i=1}^{n} 10^{SPL_i/10}\right)$$

Equation 1: Formula Used in the Calculation Method

Equation 2, seen below, results from inputting the noise averages used in Table 3 into Equation 1.

$$SPL_f = 10\log(10^{68.25/10} + 10^{68.58/10} + 10^{70.48/10} + 10^{70.68/10} + 10^{71.97/10})$$
$$SPL_f = 77.2dB$$

Equation 2: Application of the Calculation Method Formula

The result obtained using the Rule of Thumb Method (77.58 dB) is similar to the total obtained using the Calculation Method (77.2 dB) –this is not a coincidence. The Rule of Thumb Method was designed by industrial hygienists to produce a similar result to that of the Calculation Method, but the former can be calculated by hand. When using the Rule of Thumb Method, the industrial hygienist will not need to use a calculator with a logarithmic function, as with the Calculation Method.

Finally, OSHA and ACGIH use different limits for time-weighed average noise exposures, as seen in Table 4. These values are called Permissible Exposure Limits (PEL) by OSHA, and Threshold Limit Values (TLV) by ACGIH.

Table 4: OSHA PEL and ACGIH TLV for Noise Exposure

Hours of Continuous Noise Exposure	OSHA TWA PEL (dB)	ACGIH TLV (dB)
8.00	90	85
4.00	95	88
2.00	100	91
1.00	105	94
0.50	110	97
0.25	115	100

Therefore, according to Table 4, if the operator of a machine was exposed to 77.58 dB during eight continuous hours, this TWA is below the OSHA PEL of 90 dB, as well as below the ACGIH TLV of 85 dB. This means that the machine used in this example, whose noise levels were detected by means of five dosimeters, is safe to operate by OSHA and ACGIH standards, during eight continuous hours without ear protection.

Chapter 3

Review of Literature

The Ascent of Digital Printing

The printing industry is undergoing a pivotal change: print volumes are slowly migrating from conventional offset lithographic printing to digital printing. Lithographic printing, however, is likely to remain a viable technology in the long term for static, long run jobs, either as a stand-alone technology or as a component of hybrid print production. The most recent U.S. Economic Census data (2002) establishes that lithography is by far the most commonly used printing technology in the United States: 15,620 out of 34,146 printing companies (45%) are conventional, whereas 1,131 out of 34,146 (3.3%) are strictly digital printing companies. The popularity of digital technology is partially hindered by the small size and limited investment capital available to many printing companies. Therefore, conversion from conventional to digital print technologies may be economically difficult (Romano, 2001).

In the past, printing was all about mass customization, and because the economics of the process required longer runs, it was necessary to try to reach a mass audience (Romano, 2001). The new trend, however, is that run lengths are getting shorter. The new digital technologies will increasingly allow marketers to tailor their messages to ever-

smaller consumer niches. Print runs of 2,000 and under accounted for 28% of all volume in 1998, and Romano predicts that they will represent 47% in 2020 –a remarkable growth.

With the advancement and proliferation of digital technologies, the printing industry is looking forward to digital printing as a way to solve some significant technical and regulatory problems that are currently associated with traditional printing methods (M.A. Evans, personal communication, 2005). However, issues surrounding the environment and workplace health and safety do not disappear just because a printing company is using digital technologies rather than conventional printing processes. Moreover, digital technology has its own drawbacks that restrict its use for certain circumstances, such as long print runs, for which conventional technologies are more cost effective. According to Evans, if printers want to continue to evolve and succeed, it is essential for them to know and to understand how digital printing compares to traditional printing technologies in terms of its environmental, health, and safety impacts.

The Printing Industry's Environmental, Health and Safety Impacts

Conventional Printing Technologies

Twenty years ago the typical printing plant was not a pleasant place to visit: "fumes from ink and press-cleaning materials were heavy in the air, and one had to shout to be heard above the noise of the printing presses." (Bloom, 1999). The industry has limitations in meeting environmental goals at reasonable costs. When these limits are

reached, new technologies have to be developed before further progress can be made. According to Bloom (1999), it appears that the printing industry is approaching that threshold now, and we are likely to see even more change in the future as the industry struggles to balance profitability with environmental concerns. Printing companies often find it difficult to determine their impact on the environment (Envirowise, 2004), which is for the most part related to the handling of solvents and other chemicals, emissions to the atmosphere, effluent from the washing-down process, make-ready, and other substrate waste. Envirowise does not address digital printing.

Increasingly, companies need to demonstrate that they have good environmental credentials. Ferris (1995), however, said that environmental marketing can have unintended negative consequences if not handled carefully because customer concern for the environment is stronger than ever. Envirowise established in 2004 that it is beneficial to be "seen to be green" in the eyes of customers, local authorities, government environmental protection, and local residents. This means being able to demonstrate through documentary evidence, that the printing company has considered environmental issues and has taken steps to minimize adverse impacts. These impacts can be divided in two categories: direct impacts –those over which the printer has control, and indirect impacts –those over which the printer has influence. The latter are associated with the operations of material and utility suppliers, as well as product use and disposal. An environmental aspect is normally considered significant if it is controlled by legislation, has the potential to cause demonstrable harm to the environment, or is of concern to interested parties.

Printing companies whose environmental policies include waste reduction, recycling, and proper chemical disposal are realizing considerably reduced operating costs and improved manufacturing efficiencies (Burke, 1992). Such savings can result in a competitive pricing advantage, which benefits the supplier and the customer. For example, R.R. Donnelley & Sons Co. utilizes solvent recovery systems for its gravure printing operations that reduce chemical waste and save solvents. Some printers are purchasing pollution control systems and using other minimization techniques to protect the environment and avoid fines and plant shutdowns (Petersen, 1992). One problem is that too many printers worry about purchase costs but fail to consider operating or maintenance fees. Furthermore, modifying equipment to meet new regulations can be as costly as buying new equipment. In the following paragraphs the reader is presented with examples of the findings of recent environmental research projects in the industry.

Leung (2005) conducted an indoor air quality assessment in seven printing plants. His objective was to understand the effect of volatile organic compound (VOC) emissions on indoor air quality and to develop effective mitigation measures to protect workers. VOCs are carbon-containing chemicals that evaporate easily at room temperature -for this reason they are an indoor air concern. The measurements showed that, although a variety of VOCs were presented in the indoor air, none of them were close to the occupational exposure limit. However, short-term personal exposure to total VOCs was very high when a press operator cleaned the blanket and ink rollers. Therefore, the occupational health risk was mainly due to repeated short-term exposures during intermittent VOC-emitting procedures, rather than to long-term exposure.

Wadden (1995) determined emission rates during production for a sheetfed offset printing shop by combining the measured concentrations and ventilation rates with mass balance models that characterized the printing space. It was estimated that this typical small printing facility was likely to release one to two tons of VOCs per year. In cities like Los Angeles, California, printer facilities have a four-ton-per-year limit on VOC emissions. According to Gerry Bonetto of the Printing Industries Association of Southern California (Bloom, 1999), some members of the industry see this as a deterrent to growth. Since state and local regulations cannot, and should not, be circumvented, a way must be found to minimize these emissions and the overall environmental impact of printing operations if the industry is to continue to thrive locally and globally.

McMahon (1988) measured the noise exposures of 274 print production workers in 34 establishments in the New York City area. In general, a greater percentage of the workers in the bindery departments were exposed to potentially harmful noise than workers in the press departments. Results of this study indicated that many workers in the binding areas (part of the printing industry) might be at risk of occupational hearing loss.

Digital Printing Technologies

According to Kadam (2004), digital printers get most of the information about health and safety hazards from the Material Safety Data Sheets (MSDS) that come with the chemicals they purchase and from the operator manuals provided by the digital press manufacturer. Additional EHS resources (directly related to digital printing technologies) are hard to find.

The Aerias Air Quality Sciences Indoor Air Quality Resource Center website (2006) says that digital printing devices have the potential to emit dust, volatile organic compounds, and ozone. These three emissions come from the following parts and processes: the inks and toners, paper debris, coatings on transparencies, glue on adhesive labels, the mechanical print process itself, plastic materials, circuit boards, and residual cleaning chemicals.

Dust is a general term for a type of air pollution that consists of various types of particulates suspended in the air that we breathe. These particulates may come from paper debris, toners, and developers; they are small enough to be inhaled and have a variety of sizes, shapes, and levels of toxicity. Zirilli (2006) said that the accumulation of dust creates a dependability problem in digital printing devices. Toner particulates (often regarded as dust) have to be collected, transported, and separated from the main airstream, and this air must be filtered and reconditioned before being returned to the printer or the operator environment. Breathing these particulates can result in the development of respiratory diseases such as asthma, bronchitis, pneumonia and emphysema (Aerias, 2006). Wolkoff (1993) and Skoner (1990) found that particulates emitted from laser printers have been associated with headaches, mucous membrane irritation, and dryness of the throat, eyes, and nose.

In addition to respirable dust, according to Aerias (2006), of recent concern are ultrafine particulates, which are less than 2.5 micrometer in diameter. Ultrafines are a problem because they cannot be detected with the sampling equipment traditionally used to measure other particulates. The health hazards associated with the exposure to ultrafine

particulates suspended in the air are poorly understood. Researchers in California conducted a study concerning human cell damage from the inhalation of ultrafine particulates (Tran, 2003). They state that ultrafine particulates not only lodge deep inside the lungs, but also penetrate deep into the mitochondria –the power source of a human cell, and remain there indefinitely. Over time, ultrafines lodged in the cells cause severe structural damage and impair proper cell function. The U.S. government, represented by OSHA, stated in their "Occupational Exposure to Hexavalent Chromium" article (February, 2006) that ultrafines penetrate into the alveolar region of the lung, are slowly cleared from the respiratory tract, and can lead to pulmonary inflammation and respiratory disease if sufficient amounts are inhaled. The University of Rochester's Particulate Matter Center is currently testing the hypothesis that ultrafine particulates occurring in the urban atmosphere cause adverse health effects, including increased morbidity and mortality in people with respiratory and cardiac diseases (Orr, 2005).

The second emission cited by the Aerias website (2006) are volatile organic compounds (VOCs). Many of these compounds are irritants that can cause headaches, and long-term health effects of exposure to them include damage to the heart, liver, the central nervous system, as well as cancers. Some of these compounds are flammable and even toxic at high concentrations.

The third emission cited by Aerias (2006), ozone, is a highly reactive gas that is formed when air is ionized. In some digital printing processes, ozone is formed when a high voltage is applied to a corona wire before creating the image (Zirilli, 2006). Aside from being a strong lung irritant, ozone's reactive nature makes it prone to deterioration

and damage of printer components, causing a printer reliability problem. As a result, ozone needs to be collected at the source and converted back to oxygen.

Introduction to Indoor Air Quality and Applicable Regulations in the U.S.

According to the U.S. Occupational Safety and Health Administration (OSHA) website (2006) the printing industry can be separated into four main segments: lithography, flexography, gravure, and screen printing, and they must comply with all the general industry standards (29CFR1910). OSHA cites eight specific standards for lithography, one for flexography, one for gravure, and three for screen printing, but as of early 2007, there are no Federal standards for the digital printing industry.

Gary Jones (2005b) stated that conventional printers should learn about air pollution regulations that affect their businesses and discover whether or not a permit application is required by their state or local governments. He also notes that managers have to accept the fact that some level of emissions is inevitable with the current technologies. The most common regulations that must be met by all printers include those described in the following federal acts: The Clean Air Act, The Clean Water Act, The Resource Conservation and Recovery Act, The Emergency Planning and Community Right-to-Know Act, and the Comprehensive Environmental Response Compensation and Liability Act (Jones, 2005a).

Under the Clean Air Act in the 1970s, the U.S. Environmental Protection Agency (EPA) established national ambient air quality standards for pollutants believed to pose the greatest overall threat to public health and welfare (Cox, 1990). For example, the

EPA issues technical control guidelines to help states develop regulations to reduce VOC emissions from existing businesses (Petersen, 1991). The EPA lists offset lithography as one source of VOC emissions that states should consider controlling. This institution defines lithographic ink oils from web offset, sheetfed offset, and letterpress news inks as volatile because they participate in photochemical reactions.

The EPA regulates, among other things, outdoor ambient air quality; OSHA has jurisdiction over all workplace environments, but as of early 2007 no regulatory agencies control indoor air quality exposure limits. Of the estimated 100,000 toxic substances to which building occupants are potentially exposed, fewer than 400 have recommended exposure limits (Hess-Kosa, 2002).

The EPA counts indoor air pollution as one of the top environmental concerns in the continental United States. Most people spend the majority of their lives indoors and that pollution is consistently found to be two to five times higher indoors than outdoors (Hess-Kosa, 2002). The EPA issued the National Ambient Air Quality Standards with the intention of controlling emissions of six specific pollutants when released in large quantities (such as by vehicle exhausts): sulfur dioxide, total particulate, carbon monoxide, oxidants, nitrogen dioxide, and lead. Poor air exchange rates have traditionally been blamed for health complaints that have no known sources.

The health effects of poor indoor air quality depend upon the effect of each air contaminant, its concentration, duration of exposure, and individual sensitivity. In an effort to address increasing air quality health complaints, various recognized institutions have made an effort to recommend guidelines. The most prominent of these organizations

in the United States include: the American Conference of Governmental Industrial Hygienists (ACGIH), and the American Society for Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), which in turn has often credited the World Health Organization (WHO) in its efforts. During the 1990s the U.S. Department of Energy and the Department of Housing and Urban Development issued standards related to indoor air quality (Hess-Kosa, 2002).

The original OSHA exposure limits were derived from the 1968 ACGIH recommendations, and only a handful of chemical pollutants have since been updated (Hess-Kosa, 2002). Even when these chemicals have been properly identified, the OSHA limits are seldom exceeded in office environments. This is why most industrial hygienists consider OSHA limits outdated and prefer to use ACGIH guidelines (J. Heyer, personal communication, 2007). The full force of federal law, nonetheless, backs OSHA.

ACGIH is a professional society of scientists and engineers that review and recommend guidelines annually to industrial hygienists for use in the assessment of occupational workplace exposures (Schneider, 2007). Their guidelines, however, are generally limited to eight-hour exposure durations for healthy adults between the ages of 18 and 65. In 1981 ASHRAE introduced a mechanical ventilation standard that is now referred to as Ventilation for Acceptable Indoor Air Quality Standard (Hess-Kosa, 2002). The purpose of this standard is to "specify minimum ventilation rates and indoor air quality that will be acceptable to human occupants and are intended to avoid adverse health effects." This standard has since become the most commonly cited guideline for indoor air quality investigations.

The Kadam Thesis

The Kadam thesis (2004), which inspired the present study, compared EHS aspects of sheetfed offset lithography as reflected by the Heidelberg Speedmaster 74, and liquid ink-based electrophotographic digital printing as reflected by the HP Indigo 3000. These technologies are briefly explained in the following pages.

Figure 1 is a simplified cross-section view of one of the imaging units of the Heidelberg Speedmaster 74 lithographic press, whose emissions and noise levels Kadam studied.

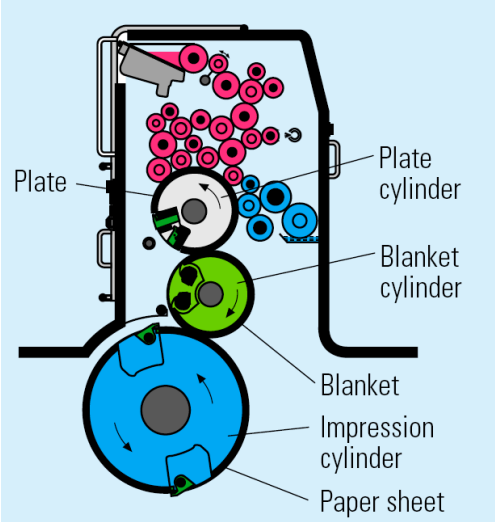


Figure 1: The Sheetfed Offset Lithographic Process on the Heidelberg Speedmaster 74 (Source: Kipphan, 2001)

The inking rollers (shown in red in Figure 1) and the dampening rollers (the five small blue circles in Figure 1) are in contact with the plate by means of the plate cylinder. The inked printing plate will roll over the circumference of the blanket cylinder, which holds

the blanket in place, transferring the ink to the blanket. The blanket, in turn, will roll over the circumference of the impression cylinder, which holds the sheet of paper. The chemical solutions that were used to clean the ink rollers, plates, and blankets were the sources of VOCs that Kadam detected. In this particular printing process, the ink on the paper is not totally dry as it arrives to the delivery pile. Therefore, to avoid smearing of the printed images, and to prevent the sheets from getting stuck together in the pile by the ink, a powder is applied to the printed sheets before they reach the delivery pile. This powder, paper debris, and undefined aerosols in the printing room were the sources of respirable and total dusts that Kadam detected in this process. The moving parts inside the Speedmaster were the source of the noise levels that Kadam recorded.

Figure 2 is a simplified cross-section view of the imaging unit that is involved in the wet ink electrophotographic process (B. Waltz, personal communication, 2007) of the HP Indigo 3000, whose emissions and noise levels Kadam studied.

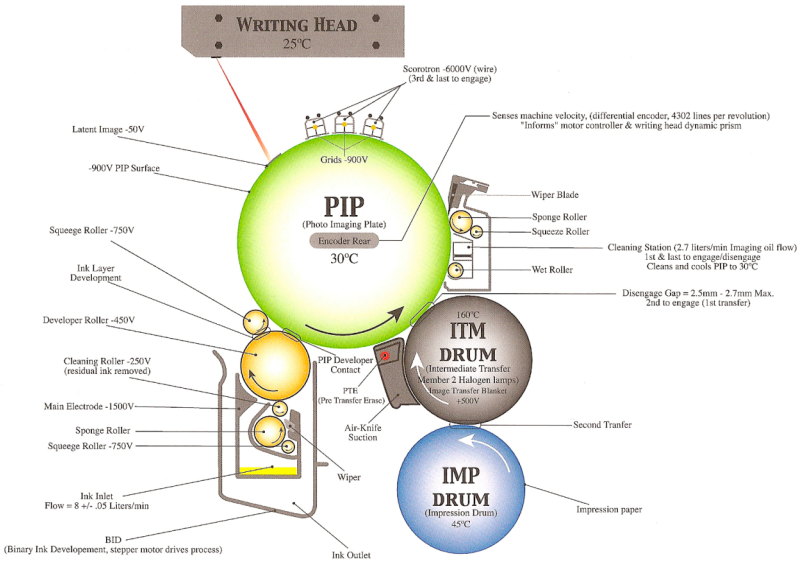


Figure 2: The Wet Ink Electrophotographic Process on the HP Indigo 3000
(Source: Printing Applications Laboratory, Rochester Institute of Technology, 2007)

The green circle in Figure 2 represents the Photo-imaging Plate (PIP), which is electrically charged by the three Scorotrons on top of it to minus 900 volts. The writing head (top of Figure 2) has 12 fine laser beams that change the voltage of the PIP from minus 900 volts to minus 50 volts only at the places where the wet ink will be adhered. The Binary Ink Developer (BID at the lower left of Figure 2) is charged to minus 450 volts. As the PIP rotates counterclockwise, the wet ink contained in the BID will be drawn to the more positive (less negative) area of the PIP (minus 50 volts) and repelled by the more negative areas (minus 900 volts). After the BID, the PIP will come in contact with the Pre-Transfer Erase (PTE module), a series of light-emitting diode lights that flash on and erase any leftover electrical charge on the PIP.

The PIP will then come in contact with the Intermediate Transfer Member (ITM) drum, which holds a heated blanket charged to a positive 500 volts. At this juncture almost 100% of the ink is transferred to the ITM because this ink is designed to be attracted to positive charges. The blanket also acts as a fuser because it is heated to 320 degrees Fahrenheit (°F). Finally, the paper passes through, squeezing between the ITM drum and the impression cylinder; this is where the ink reaches the paper.

After the ITM drum, the PIP will come in contact with the cleaning station, which pours cool imaging oil that scrubs any wet ink that may not have gotten transferred to the paper. The imaging oil is the source of the VOCs that Kadam studied. Paper debris and undefined aerosols in the printing room were the sources of respirable and total dusts that Kadam detected in this process. The moving parts inside the HP Indigo 3000 were the source of the noise levels that Kadam recorded.

Table 5 is a comparison of the environmental, health, and safety aspects studied by Kadam and by the author.

Table 5: Comparison of Environmental and Occupational Aspects Studied by Kadam in 2004 and by Leal in 2007

EHS Aspect Analyzed	Kadam	Leal
Carbon Dioxide Concentrations	NO	YES
Relative Humidity Levels	NO	YES
Temperature Levels	NO	YES
Respirable Dust Concentrations	YES	YES
Ultrafine Particulate Concentrations	NO	YES
Total Dust Concentrations	YES	YES
Volatile Organic Compound Concentrations	YES	YES
Ozone	NO	YES
Noise Level Survey	YES	YES
Material Utilization	YES	NO

The following is a summary of the Kadam findings that are relevant to this study:

- Total dust concentrations are slightly higher in the digital printer than in offset lithography; however, all are well below PEL.
- Respirable dust concentrations are similar in both processes and below PEL.
- VOC emissions from both presses are below regulatory standards.
- VOC emissions in the digital press increase proportionally with print volume.
- VOC emissions in offset lithography do not increase significantly with an increase in print volume.
- Occupational noise exposure is well below OSHA PEL in both processes.

A mass balance experiment was involved in the Kadam thesis for the purpose of calculating Material Utilization (see the last row of Table 5). The author chose not to conduct this experiment because Hewlett-Packard, the manufacturer of the Indigo 3000, raised numerous objections to the Kadam mass balance methodology and results (M.A. Evans, personal communication, 2006). Kodak's Advanced Technology Chief Engineer also did not approve of the idea of a mass balance experiment given the cost and time restrictions of this project:

> The issue was that the time needed to get meaningful data was not practical (i.e., enough). For example, in order to get 100 grams of toner waste you would need to run about 10,000 pages but 100 grams is barely enough to prime the waste system so the amount that you would collect in the waste bottle could be much smaller depending on the state of the machine prior to the start of the test. In addition the amount of waste generated is highly dependant on the type of job that you run (single sided, or double coverage, etc.) and the state of the machine. To get statistically significant data for mass balance you would likely need to run a few hundred thousand prints with a variety of images. I didn't think that was practical (T.N. Tombs, personal communication, 2006).

The NexPress 2500 and its Environmental Footprint

NexPress started as a joint venture between the Eastman Kodak Company and Heidelberg, and in early 2003 Heidelberg sold all its interests in this venture to Kodak (J. Vanslette, personal communication, 2006). The NexPress 2500 owes its name to the fact that it can print up to 2,500 sheets (12 by 18 inches) per hour. It is a digital color press with a 600 dots-per-inch resolution, and is advertised as having a reliability and usable lifetime similar to those of lithographic presses (Kodak Graphic Communications Group, 2006). This press uses dry toner electrophotographic technology to print digital data directly onto the substrates.

The printing system has two major components: the Kodak NexPress 2500 digital print engine and the Kodak NexStation Front End (Kodak Graphic Communications Group, 2006). This last component is where the digital files are ripped, trapped, compressed, and queued for printing, and it enables remote access through the customer's network with remote client software. The NexPress has four electrophotographic printing units for black, yellow, magenta, and cyan dry toners. It has a fifth (optional) imaging unit that accepts red, green, or blue for color gamut expansion, or a clear dry toner for image protection and enhancement (Ng, 2006).

Figure 3 shows the main components involved in this printing process.

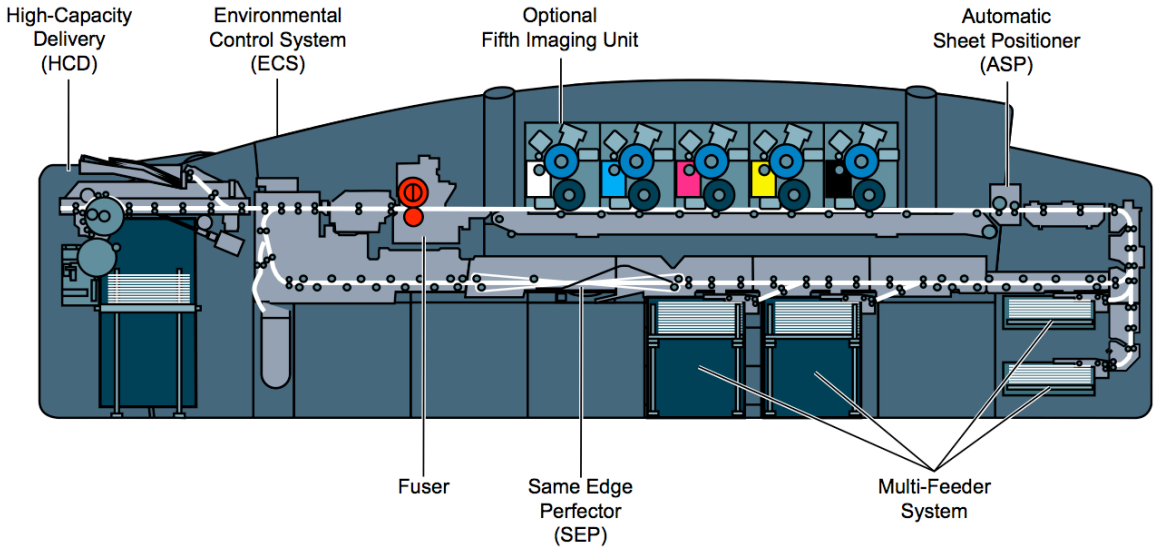


Figure 3: Cross-section of the NexPress (Source: Kodak G.C.G., 2007)

Ng (2003) describes this dry toner digital printing process as follows:

1. Media are released from the paper feeders (lower right of Figure 3) and pass to the Automatic Sheet Positioner (ASP, top right of Figure 3).
2. The ASP places the media on the Web Transport, which carries it to the five imaging units (top center of Figure 3) and color toner separations are transferred to the media sequentially in registration.
3. The media are then passed on to the fuser and cooler units, which use media-dependent fusing technology.
4. If the image is printed on only one side of the media, it can be delivered to either a proof tray or a main delivery unit (top left of Figure 3). For two-sided printing, the media is passed to a perfecting unit at full speed.

Ng (2003) uses Figure 4 to explain how the toner transfer process (step 2 of the previous list) takes place in each imaging module. The paper transfer nip is shown as an inset on the right side of Figure 4.

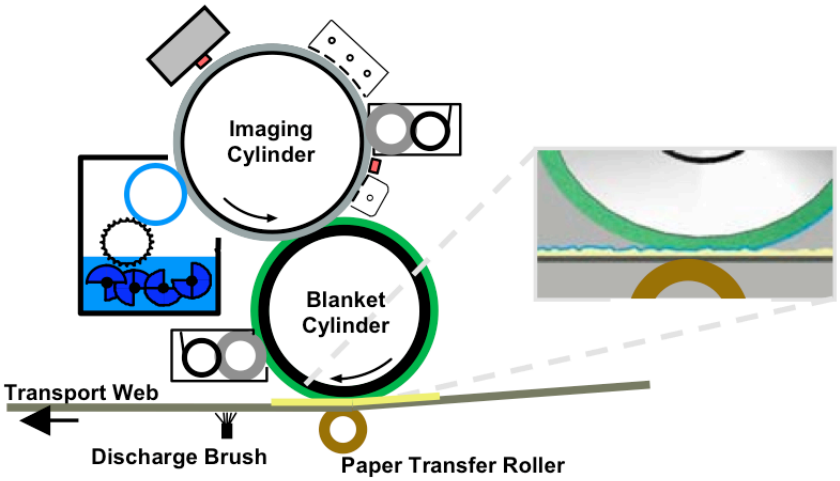


Figure 4: Schematic of the NexPress Imaging Module (Source: Ng, 2003)

According to Ng (2003) the blanket cylinder (BC) is driven by an insulating endless web, which is backed by a roller that defines the transfer geometry in this nip. Dry toner is electrostatically transferred from the imaging cylinder (IC) to the BC with a constant voltage supplied to the core of the BC. The electrostatic transfer force is maintained in the nip by a constant current supplied to the core of the paper transfer roller that charges the backside of the web and induces a polar charge on top of the media as it exits the nip; the net charge is eliminated with a discharge brush. The image is then fixed to the media by means of a heated fuser, which has a pneumatic pressure mechanism that allows it to fix images on different medias of varying weight and thickness. After fusing, the media is

separated from the fuser roller with an air knife. This air stream cools the media before it passes through the cooler module. The process is then complete, and the media exits the press or is flipped for printing on its other side.

The NexPress manages its environmental impacts through the following systems: a contamination control (CC) subassembly, a waste management (WM) system, and an environmental control system (ECS). The CC uses airflow to help remove waste dry toner and environmental contaminants from the press. The WM uses both mechanical components and channeled airflow to control and to remove waste contamination from the press. The purpose of the ECS is to provide the following conditions inside the press: air at 70 °F, a relative humidity of 35% ± 5%, and non-conditioned air with controlled and filtered flow.

Chapter 4

The Research Statement

This research project has reproduced a proven methodology for quantifying various environmental aspects of digital printing as reflected by the Kodak NexPress 2500. This study has proved or disproved the following hypotheses:

1. The Material Safety Data Sheets (MSDS) of the fuser fluid, dry toners, and developers of the NexPress 2500 do not reveal the presence of any recognizable VOCs, as opposed to the MSDS of the HP Indigo 3000 imaging oil, which reveals the presence of a VOC identified simply as petroleum hydrocarbon, Chemical Abstracts Service number 90622-58-5.
   Thus, the first hypothesis is $\boldsymbol{H_0 1}$: VOC emissions are higher in liquid ink digital printing and sheetfed offset lithography when they are compared to dry toner digital printing VOC emissions, both in short and long runs.

2. This hypothesis is based on the fact that the NexPress 2500 is equipped with three sophisticated and independent contamination control, environmental control, and waste management systems whose purpose is to remove dry toner and environmental contaminants from the press.

Thus, the second hypothesis is ***H_o2:*** Respirable dust level emissions are higher in liquid ink digital printing and sheetfed offset lithography when they are compared separately to dry toner digital printing respirable dust emissions, both in short and long runs.

3. This study was started under the assumption that dry toner digital printing is inherently "cleaner", or more environmentally friendly, than either wet ink digital printing or sheetfed offset lithography. At the time this hypothesis was conceived, the author was not aware of any evidence that pointed in either direction.

   Thus, the third hypothesis is ***H_o3:*** Eight-hour, time-weighed average noise levels are higher in liquid ink digital printing when they are compared to dry toner digital printing levels, in short and long print runs.

Chapter 5

Methodology

A similar methodology to the one used by Kadam (2004) was deployed. There are several differences, however, between the two projects: Kadam does not include analysis of carbon dioxide, relative humidity, room temperature, ultrafine particulates, and ozone. With the NexPress 2500 digital production color press selected as the primary resource of the study, raw materials were selected, and the length of the print runs was determined. Following Kadam's example, 30 minutes was chosen as the length of the short run, and two hours as the length of the long run. Three Kodak scientists and two NexPress operators validated these run lengths.

Two types of print runs were executed: preliminary and experiment. The purpose of the preliminary runs was to become familiar with the measuring devices and their data logging procedures; these techniques had been learned by the time the experiment runs took place. In all instances a trained professional downloaded the data (after the print runs) from each of the instruments to a personal computer using the software provided with each device.

Another significant difference between the preliminary and the experiment runs was that the order of the print runs (short and long) was inverted. This was done to see if

an apparent anomaly and some periodic events that were observed during the preliminary runs would repeat themselves during the experiment runs. The outcome is discussed in the Results chapter of this document.

The Checklist Used During the Print Runs

The following two paragraphs are transcripts of the checklists used before, during, and after the preliminary and the experiment run.

First, the volume of the room where the print runs took place was measured by multiplying its length by its width by its height. The instruments were connected to the wall outlets (no batteries were used), turned on, and allowed to warm up and settle for 15 minutes. When the instruments were ready, background measurements were made and written down for all of them. Digital pictures were taken of the position of the instruments around the NexPress, and a sketch was made of the printer and the relative position of any and all the other machines in the room. The serial numbers of the total dust filters and air pumps were written down as part of the sketch; the same was done with the noise dosimeter codes.

Once the print runs started, all events were logged together with their corresponding start and finish. Ozone concentration levels had to be logged manually because the instrument does not save this data. When the print runs were finished, a digital copy of the file that was printed was retrieved, and so were five printed sheets.

The Digital Printing Device

Two different Kodak NexPress 2500 digital production color presses were used; one on the preliminary run, and the other on the experiment run. They were located in different rooms of the Kodak Manitou facility in Gates, New York. The fuser fluid, the five dry toners (cyan, magenta, yellow, black, and clear), and the five corresponding developers were the standard consumables that Kodak sells for use with this particular digital press.

Choice of the Paper

The paper used was the Navajo Text, manufactured by Mohawk: its weight is 118 grams per square meter, it was trimmed down to 12 inches long by 18 inches wide, and its grain was located along the latter side. The paper was chosen because, according to Manitou NexPress operators, it is readily available to NexPress customers in the U.S., has good curl resistance, allows excellent image contrast, and has been qualified (approved) by Kodak to run on the NexPress 2500.

Choice of the Print Target

Figure 5 is a screenshot of the image that was printed on both sides of the paper.

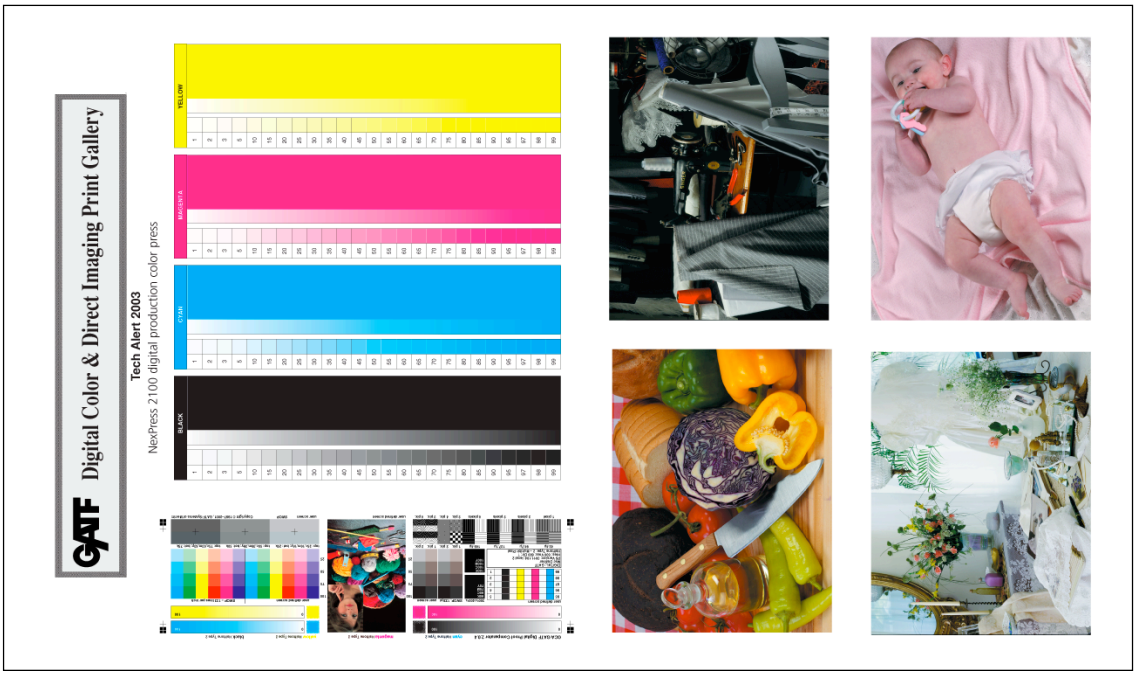


Figure 5: Screenshot of the Digital File GATF_Sample_tagged_baby.pdf
(Source: Kodak, 2006)

This file was printed on both sides of the paper in order to maximize printer emissions, and it was chosen because it is similar to the file used by Kodak Manitou NexPress operators to test general color production performance variables, such as overprints, shadow detail, highlights, skin tones, memory colors, the four process colors, vignettes, grayscales, and fine line targets for evaluation of resolution.

Measurement of Ventilation Parameters

Carbon dioxide (CO_2), relative humidity, and room temperature were measured using the 8554 Q-Trak Indoor Air Quality Monitor, seen in Figure 6. The Q-Trak was placed in the operator station in all print runs.

Figure 6: The Q-Trak Indoor Air Quality Monitor and Its Probe (far right)

The Q-Trak uses a Non-Dispersive Infrared Absorbance (NDIR) sensor to monitor CO_2. It has a range of zero to 5,000 parts per million (ppm), an accuracy of ± 3% of reading at 77 °F, and a resolution of one ppm. The principle behind the NDIR is that most molecules can absorb infrared light, causing them to bend, stretch, or twist. The amount of infrared light absorbed is proportional to the concentration of the molecules. CO_2 has a strong absorbance at 4.26 micrometers as seen in its infrared spectrum; this absorbance band is specific to this molecule. Given a fixed sensor cavity depth,

measuring the light intensity before and after the sample allows a measurement of the concentration. According to the Q-Trak Operation and Service Manual (2006), the gas sample diffuses into the cavity through a metal frit on the top of the instrument. Polychromatic light from an incandescent bulb passes through the gas sample and is absorbed in proportion to the amount of CO_2 present. The filter in front of the detector removes all of the light except at 4.26 micrometers, corresponding to CO_2. This device conforms to the EPA Method 3A, Title 40 Code of Federal Regulations (CFR) 60, Appendix M.

The Q-Trak uses a thermistor to measure temperature. It has an effective range of 32 to 122 °F, an accuracy of ± 1 °F, and a resolution of 0.1 °F. The thermistor is a thermally sensitive resistor that exhibits a change in electrical resistance when it is subject to a change in temperature. The resistance decreases with an increase in temperature, and the instrument has a built-in algorithm that uses a calibration curve (a detailed matrix) that compares the expected resistance values at various temperature points across the aforementioned range, and this is the temperature that the instrument finally displays and logs.

The Q-Trak uses a thin-film capacitive sensor to measure relative humidity. It has a range of five to 95% relative humidity, an accuracy of ± 3%, and a resolution of 0.1%. The sensor operates on the principle that changes in relative humidity cause the capacitance of the sensor to change in a detectable and repeatable manner. The sensor itself is a combination of a substrate, electrodes, and a thin film of hygroscopic (a substance that tends to absorb moisture from the air) polymer material. As with the

temperature, this instrument has a built-in algorithm that uses a matrix to compare the expected capacitance values at various relative humidity percentages, and this is the percentage that the instrument displays and logs.

The Q-Trak undergoes a factory calibration once a year. The following procedure was used in order to take measurements:

1. Turn the Q-Trak on and allow it to warm up for one minute.
2. Press Sampling Mode until Log Mode 1 is displayed.
3. Press the Sample key; the Q-Trak will measure and log CO_2, relative humidity and temperature simultaneously.
4. At the end of measurements, press the Sample key and turn the Q-Trak off.

The Q-Trak logged CO_2 levels in parts per million, relative humidity as a percentage, and temperature in degrees Fahrenheit. These three variables were analyzed separately, and they were plotted in the y-axis of a graph where the x-axis represented the time of day in hours, minutes, and seconds. This allowed visual comparison of each level to its corresponding OSHA and ASHRAE recommendation for maximum and minimum acceptable exposure levels.

Measurement of Respirable Dust

Respirable dust was measured using the 8520 DustTrak Aerosol Monitor, which was placed in the operator station in all runs. The DustTrak, seen in Figure 7, has an aerosol concentration range of 0.001 to 100 milligrams per cubic meter (mg/m^3), and a particulate size range of 0.1 to 10 micrometers. This instrument uses a pump to draw air through the 2.5 micrometer-wide discriminator and impacts the suspended dust against a plate. Dust particulates greater than 2.5 micrometers contact and adhere to this plate, thus being removed from the air stream. Particulates smaller than this are suspended in the air and are drawn into the DustTrak. The stream is directed between a light source and a detector; the latter measures the amount of transmitted light, which is inversely proportional to the mass of respirable dust present in the sample. This information is then displayed as milligrams per cubic meter.

Figure 7: The 8520 DustTrak Aerosol Monitor

The DustTrak monitor conforms to EPA Method 5, and it is sent to the manufacturer for calibration and maintenance once a year. The following set of instructions was used to confirm the zero point of the device, in accordance to the 8520 DustTrak Operation and Service Manual (2006):

1. Insert the 2.5 micrometer impaction plate and nozzle into the inlet of the DustTrak (located on the front).
2. Turn the DustTrak on and allow it to warm up for one minute.
3. Attach the zero filter to the 2.5 micrometer nozzle.
4. Press the Time Constant key until 10 is displayed, then release.
5. Wait until the measured values reach zero; this may take up to one minute.
6. The DustTrak should settle on a value between –0.001 and +0.001 mg/m^3. If the displayed value is not within this range, follow steps 1-5.
7. Press and hold the Calibrate key until the display timer reaches zero, then release. "Calibrate Zero" should be displayed; if not, then repeat steps 1-6.
8. Press the Sample key and allow the one-minute countdown to complete.
9. The zero is now stored. To return to survey mode, press the Calibrate key.
10. Connect the provided flowmeter to the 2.5 micrometer inlet.
11. Use the provided screwdriver to adjust the screw controlling the flow rate (located on the front of the DustTrak) such that the flowmeter reads 1.7 l/m.
12. Disconnect the flow meter and connect the sampling tubing to the 2.5 micrometer inlet.

The following procedure was used to take measurements:

1. Confirm the zero of the DustTrak following the previous set of instructions.
2. Press the Sampling Mode key until Log 1 is displayed.
3. Press the Sample key to begin recording; “Recording” should be displayed.
4. At the end of the sampling period, press the Sampling Mode key until Survey Mode is displayed.
5. Turn the DustTrak off.

The DustTrak logged respirable dust concentrations in milligrams per cubic meter. These concentrations were plotted in the y-axis of a line graph where the x-axis represented the time of day in hours, minutes, and seconds. This allowed visual comparison of the respirable dust concentration to the corresponding OSHA PEL, the ACGIH recommendation, and the Kadam results.

Measurement of Ultrafine Particulates

Ultrafine particulates were measured using the TSI 8525 P-Trak Ultrafine Particulate Counter, seen in Figure 8. This instrument was placed in the operator station in all print runs.

Figure 8: The 8525 P-Trak Ultrafine Particulate Counter

The P-Trak has a concentration range of zero to 500,000 particulates per cubic centimeter, a sample rate of 100 cubic centimeters per minute, and a particulate size range of 0.02 to one micrometer. This instrument draws in air using a pump and uses a fixed filter system to screen out particulates greater than one micrometer. The collected particulates are then enlarged by the introduction of 99.5% pure isopropyl alcohol. These enlarged particulates are then made to pass between a light source and detector, where the latter measures the amount of transmitted light.

As with the DustTrak, here the amount of light detected is inversely proportional to the number (not the mass) of ultrafine particulates present in the sample. This data is then displayed as the number of ultrafine particulates per cubic centimeter.

This device is sent to the manufacturer annually for calibration and maintenance. The following instructions were used in order to confirm the zero point of the device, according to its Operation and Service Manual (2006):

1. Turn the P-Trak on and allow it to warm up for one minute.
2. Attach the provided zero filter assembly to the P-Trak.
3. The particulate count displayed should read zero after five to ten seconds.
4. After zero has been reached, allow the P-Trak to continue running for 30 seconds, checking that the zero reading is stable. If a stable zero is not reached, turn the P-Trak off, remove the zero filter assembly, and repeat steps 1-4.
5. Remove the zero filter assembly.

The following procedure was used to take measurements:

1. Insert the inlet screen assembly into the inlet located on the front.
2. Unscrew the storage cap from the front of the P-Trak.
3. Remove the alcohol cartridge from the alcohol container.
4. Gently shake the alcohol cartridge in order to drain excess alcohol on the cartridge back into the alcohol container.

5. Insert the alcohol cartridge into the front of the P-Trak, locking it into place with a 45-degree turn.
6. Seal the alcohol container with the storage cap (from step 2).
7. Confirm the zero point of the P-Trak (see the preceding procedure).
8. At the main menu, use the down arrow key to highlight the Log Mode option.
9. Use the left and right arrow keys until "Log Mode 1" is displayed; then press the Enter key.
10. At the end of the sampling period, turn the P-Trak off.
11. Unscrew the alcohol cartridge from the P-Trak.
12. Screw the alcohol cartridge into the alcohol container.
13. Screw the storage cap into the front of the P-Trak.

The P-Trak logged the number of ultrafine particulates per cubic centimeter. These concentrations were plotted in the y-axis of a line graph where the x-axis represented the time of day in hours, minutes, and seconds. This allowed visual comparison of the results from the preliminary and experiment runs.

Measurement of Total Dust Concentration

Total dust was measured using four MSA International ESCORT ELF air pumps and the air cassettes that are provided with them. The pump draws air through a cassette containing two filters that are pre-weighed and identical in mass. Air was allowed to pass through one filter, and all particulates larger than five micrometers were retained. When the experiment was complete, the filters were weighed in a laboratory to determine the mass of dust captured. The second filter was not allowed to accumulate any dust but also was weighed to adjust for absorption of water vapor from the environment. The ESCORT ELF air pumps and the air filters are seen in Figure 9.

Figure 9: ESCORT ELF Air Pump and Air Cassettes

Four pumps and their corresponding cassettes were placed four feet around the NexPress using a North-South-East-West configuration in all print runs. The device was calibrated according to its Instruction Manual (1997):

1. Insert the outlet of the cassette into the inlet tubing of the pump.
2. Attach the inlet of the cassette to a flowmeter.

3. Turn the flowmeter on.
4. Turn the pump on and adjust its flow rate until the flowmeter reads 2 l/m.
5. Repeat steps 1-4 until two consecutive results are within 2% of each other.

The following procedure was followed in order to take measurements:

1. Attach the cassette, tubing, and pump to the location of interest.
2. Check the pump assembly at least once every two hours for proper operation.
3. At the end of the experiment, reinsert the assembly into the calibration setup.
4. Without adjusting the pump flow rate, record the flow rate of the pump as displayed by the flowmeter, and turn the pump off.
5. Remove the cassette from the pump, and then seal the inlet and outlet.
6. The final phase was to send the dust cassettes to a laboratory for analysis. Kodak chose Galson Laboratories in East Syracuse, New York, for this task.

The laboratory reported the mass of dust particulates retained in the air filters using NIOSH Analytical Method 500 (NIOSH is the National Institute for Occupational Safety and Health). This gravimetric method is based on the principle that the difference in weight of a filter before and after collecting the sample will yield the mass of dust or particulate matter retained on the filter, after moisture has been removed. Dividing the reported mass by the volume of the room where the measurements took place yielded the concentration of total dust in the corresponding rooms. This concentration was compared to the total dust OSHA PEL, the ACGIH recommendation, and the Kadam results.

Measurement of Volatile Organic Compounds

Volatile organic compound emissions were measured using the TVA-1000B Organic Vapor Analyzer. This device has an accuracy of ± 2.5 ppm from one to 10,000 ppm, and a sample rate of one liter per minute. The TVA-1000B is seen in Figure 10. This instrument was placed in the operator station in all print runs.

Figure 10: The TVA-1000B Organic Vapor Analyzer and Its Probe (above it)

According to the instrument's Instruction Booklet (1996), the TVA-1000B takes the incoming sample air stream and passes it through a photo-ionization detector (PID). This detector uses an ultraviolet (UV) light lamp to energize the incoming molecules. This charged gas carries an electric current that can be measured by the device.

The gas then passes through the flame-ionization detector (FID), which measures organic compounds by utilizing a flame produced by the combustion of hydrogen and

air. When hydrocarbons in the sample are introduced to the detection zone, ions are produced. A collector electrode with a polarizing voltage also is located within the detector chamber, and the ions produced by this reaction are attracted to it. As the ions migrate toward the collector, a current is produced that is directly proportional to the concentration of hydrocarbons introduced to the flame. This current is then amplified and sent to a microprocessor and an analog readout device. This study did not make use of the PID data, only the FID data, because the latter is more responsive to a wider range of volatile organics.

The calibration of the vapor analyzer sets the background level (zero point) of the electrical current produced in the detectors. A gas called Span of known concentration is used to calibrate the vapor analyzer to a known electrical current produced by that particular concentration.

The following set of instructions was followed in order to calibrate the device according to the TVA Instruction Booklet (1996):

1. Turn the vapor analyzer on and allow it to run for 30 minutes in ambient air.
2. From the Main Menu, press 2 (Setup), followed by 1 (Calibration).
3. Press 2 (Background), followed by 1 (Both).
4. Introduce the calibration gas into the probe.
5. Press Enter: if the calibration was successful, the word “Accepted” will be displayed; if not, follow steps 1-4 again until it does.
6. Press Exit until the Calibration Menu is displayed.

7. Press 3 (Span), and then press 1 (Both). Press 4 (Gas Conc), and then press 1.
8. Use the up and down arrow keys to select the unit (%, PPM, or PPB) of the calibration gas concentration. In these experiments, the author used PPM.
9. Type the numerical concentration of the calibration gas, and then press Enter.

This is the procedure that was followed in order to take measurements, according to its Instruction Booklet (1996):

1. Screw the sampling nose onto the wand, and connect the tubes to the analyzer.
2. Screw the hydrogen tank into the side of the vapor analyzer. Note that the threads for the hydrogen tank are reversed.
3. Switch the red hydrogen cutoff valve to the open position.
4. Turn the vapor analyzer on and wait 15 seconds for the Main Menu to display; then press the Control button.
5. Press 1 (turns pump on), then press Control, and then press 2 (Ignite).
6. If the FID flame fails to ignite, repeat steps 1-5.
7. At the Main Menu, press 1 (Run) and measure for as long as planned.
8. On the probe, press the button labeled Log.
9. At the end of the sampling period, turn the instrument off.

The TVA-1000B logged the concentration of VOCs in parts per million using EPA method 25A. These concentrations were plotted in the y-axis of a line graph where

the x-axis represented the time of day in hours, minutes, and seconds. This allowed visual comparison of the VOC concentrations for preliminary and experiment data.

Measurement of Ozone Concentration

Ozone concentration was measured using the Dasibi 1008 UV Photometric Ozone Analyzer, and it conforms to EPA Method 411 (Lodge, 1989). This instrument has a range of zero to 1,000 ppm, a sensitivity of 0.001 ppm (or one part per billion), an accuracy of ± 1%, and a flow rate of three liters per minute. The ozone analyzer and the device used to calibrate it are seen in Figure 11. This instrument was placed in the operator station in all print runs.

Figure 11: The Dasibi 1008 UV Photometric Ozone Analyzer and the Primary Standard

This instrument uses a pump to draw in air and splits the air stream into two pathways. One pathway contains a scrubber that removes any ozone before entering an optical chamber; the other pathway leads directly to its own optical chamber. The optical chambers have an ultraviolet (UV) light source and a detector. UV light passes through

the sample, and the detector measures the amount of transmitted light. The clean sample is used to correct for other gases and contaminants in the air that may reduce this transmission of light. The amount of light detected is inversely proportional to the concentration of ozone.

The calibration process involves connecting the ozone analyzer with a primary standard, certified by the National Institute of Standards and Technology (NIST) and seen at the right of Figure 11. According to Wight (1994), a primary standard is a "standard meter" known to be correct or more precise and accurate than the ozone measuring device, and it typically has a resolution of ± 0.3%.

The following set of instructions was used to confirm the accuracy of the ozone analyzer against the primary standard according to its User Manual (1990):

1. The primary standard should be connected to an exhaust system to capture and treat the ozone generated.
2. Connect the ozone analyzer to a three-way valve in the exhaust system.
3. Turn the ozone analyzer on, and then turn the primary standard on.
4. Set the ozone analyzer to a flowrate of two liters per minute using the dial on the front of the ozone analyzer.
5. Set the primary standard to generate 100 parts per billion (ppb) of ozone, using the up and down arrows located on its front.
6. Allow the devices to equilibrate for 15 minutes.
7. Confirm that the readings on the ozone analyzer are within ± 5 ppb of the primary standard.

8. Turn the primary standard off, and then allow the exhaust system 15 minutes to remove any remaining ozone. Turn off and remove the ozone analyzer.

The following procedure was used to take measurements according to the Ozone Analyzer's User Manual (1990):

1. Connect the inlet and outlet tubing to the ozone analyzer (located on the back of the machine).
2. Place the other ends of the tubing in the area of interest.
3. Turn the ozone analyzer on.
4. Adjust the flowrate to two liters per minute using the knob on the front of the ozone analyzer.
5. Allow the instrument to settle for 15 minutes.
6. When sampling begins, record the displayed value on the ozone analyzer manually. The instrument is not designed to log data for the user.

The UV Photometric Ozone Analyzer displayed (did not log) the concentration of ozone in parts per million, which were then converted to parts per billion. These concentrations were plotted in the y-axis of a line graph where the x-axis represented the time of day in hours, minutes, and seconds. This allowed visual comparison of the ozone concentrations to the OSHA PEL.

Measurement of Noise Level

Noise levels were measured using CK110 doseBadge Noise Dosimeters and a Reader Unit, all seen in Figure 12. The doseBadge meets standards IEC 61252:1993 Personal Sound Exposure Meters, and the American National Standards Institute (ANSI) S1.25:1991 Personal Noise Dosimeters. The Reader meets Internal Acoustic Calibrator IEC (International Equipment Center) standard 60942:2001 Class 2.

The doseBadge has a range of 70 decibel (dB) to 130 dB time-weighed average, and 120 to 140 dB as peak sound pressure. The noise dosimeters and the reader unit are seen in Figure 12. Four units were placed around the NexPress, and the operator wore a fifth one at shoulder height. The dosimeters were placed around the four sides of the machine using a North-South-East-West configuration during the experiment run; a sketch of this distribution can be seen in the Results chapter of this document. Each dosimeter was assigned a specific color that identified it throughout this study.

Figure 12: The CK110 doseBadge Noise Dosimeters and the Reader Unit

According to its operation manual (2006), the doseBadge uses a microphone to pick up the energy levels of incoming sound waves. The microphone works by using a thin diaphragm made from a thin piece of metal that is made to vibrate by sound waves.

The vibration of the diaphragm causes a ceramic element to oscillate, thereby bending a fulcrum that generates an electrical current. Finally, the magnitude of the current is converted to decibels. The doseBadges and the Reader communicate via infrared ports.

The manufacturer calibrates the Reader unit annually. The following procedure was used in order to take noise measurements:

1. Turn on and position the Reader unit within four inches of the doseBadge, having the infrared ports on the doseBadge and the Reader unit facing each other. Turn on the doseBadge.
2. Press the Run key. Wait until the status of the unit reads OK.
3. Repeat steps 1-2 for all doseBadges used.
4. Press the Stop key and wait until the status of the Reader reads OK.

The five doseBadges transmitted the noise levels they detected (in decibels) to the Reader unit. These noise levels were plotted separately in the y-axis of a line graph (one graph for every noisemeter) where the x-axis represented the time of day in hours, minutes, and seconds. This allowed visual comparison of the noise levels to the time-weighed average OSHA PEL, ACGIH TLV, and the Kadam results.

Limitations of the Methodology

The preceding methodology was designed specifically for the Kodak NexPress 2500 and the standard consumables that Kodak sells for it. None of the methods, results, or conclusions of this study can be compared to those of Kadam (2004) for mass balance, material consumption, resource utilization, nor waste measurement.

Chapter 6

Analysis of Experimental Results

Two types of print runs were executed: preliminary and experiment runs. Preliminary runs were conducted in a smaller office environment than the experiment runs. The order of the print runs (short and long) was deliberately inverted during the experiment runs. In the following pages the reader will be presented with stacked graphics; the graph on top corresponds to preliminary run data (labeled A); the lower graph represents experiment run data (labeled B). The scale of each pair of graphs is identical in both axes in order to simplify visual comparison.

Carbon Dioxide, Relative Humidity, and Temperature

Figure 13 shows the carbon dioxide (CO_2) readings detected by the Q-Trak.

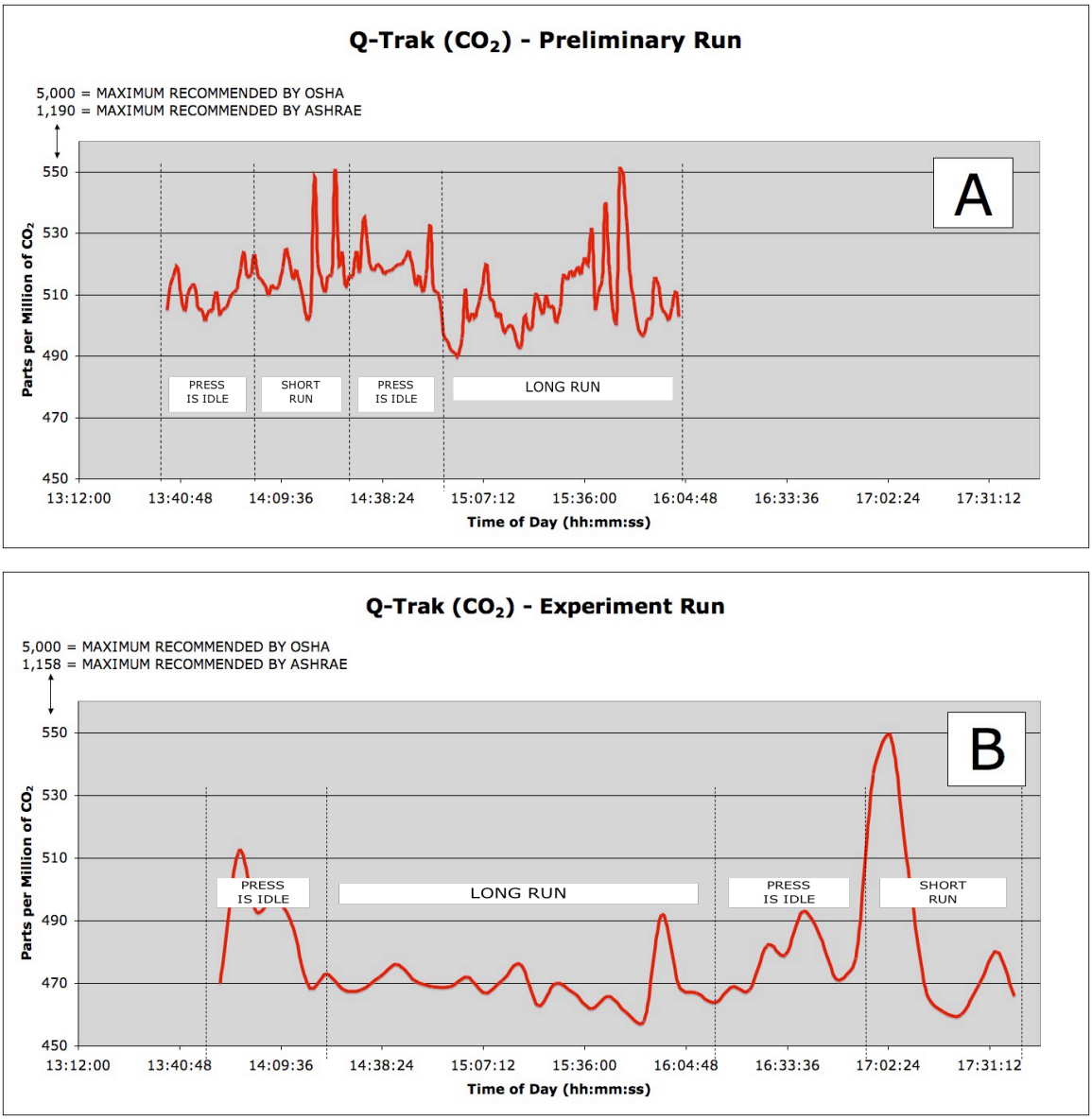


Figure 13: CO_2 Readings During the Preliminary (A) and Experiment (B) Runs

In their Standard 62.1-2004 (Ventilation for Acceptable Indoor Air Quality), the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) provides the ventilation guideline of 700 parts per million (ppm) of CO_2 above background as a measure of the quality of the indoor air. If this guideline is followed, odors and other indoor air contaminants should also be acceptable (J. Heyer, personal communication, 2007). OSHA, on the other hand, provides a permissible exposure level of 5,000 ppm in Table Z-1 of Standard 29CFR1910.1000. OSHA represents the U.S. government, and ASHRAE represents the private sector.

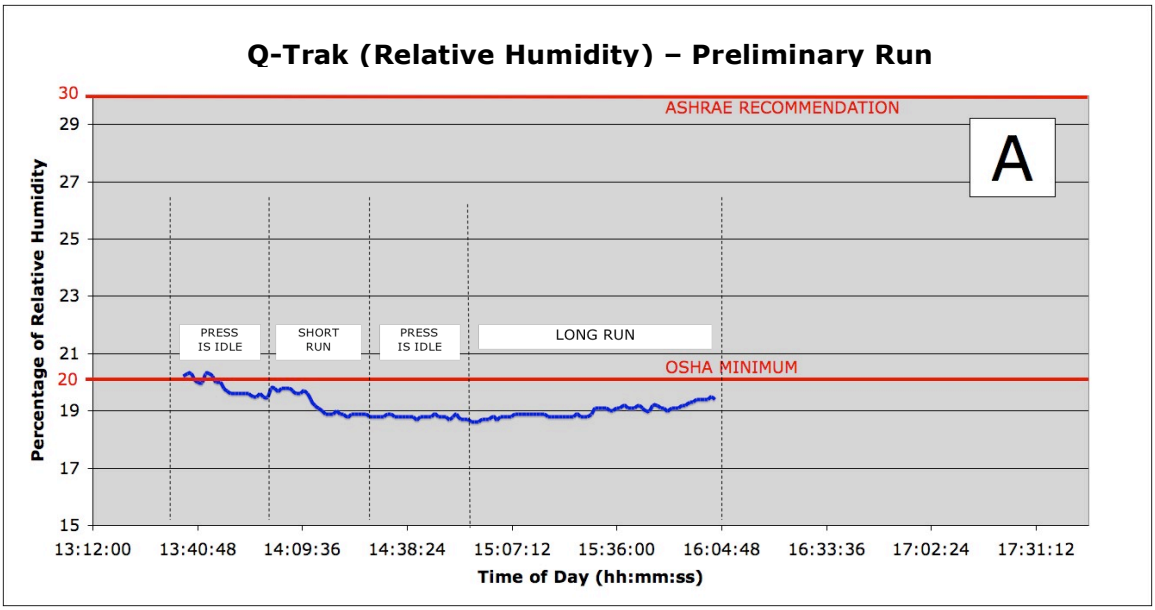
Background levels were 490 ppm in the preliminary and 458 ppm in the experiment run. CO_2 levels were below 600 ppm in both runs, almost one order of magnitude lower than the OSHA PEL of 5,000 ppm, and less than half of the ASHRAE limit. To put these values in perspective, normal outdoor concentrations of CO_2 range from 250 ppm to 350 ppm.

The cycles in both curves –approximately every six minutes in Figure 13A, and every eight minutes in Figure 13B– can be explained by the fact that the intake of the Q-Trak and the intake of the ozone analyzer were located side by side in the operator's breathing zone. Every time the author approached the analyzer to record its readings manually (every six minutes in the preliminary runs, and every eight minutes in the experiment runs), the air exhaled by the author would trigger these spikes. The larger spikes correspond to moments when three or four people stood near the instrument's intake.

CO_2 concentration in an office environment is a surrogate for assessing indoor air quality (J. Heyer, personal communication, 2007). CO_2 occurs as a product of human respiration. According to Heyer, the CO_2 detected inside occupied spaces is typically a combination of natural background and human respiration. He stated that it is highly unlikely that the operation of the NexPress had any direct effect on CO_2 levels in either room. The concentration of this gas was measured to see how well fresh air (supplied through the ventilation system of the rooms) was able to dilute indoor air contaminants.

The meaning of the preceding results was that the operation of the NexPress does not result in a significant rise of CO_2, and that the rooms in which these presses are located are well ventilated according to ASHRAE and OSHA.

Figure 14 shows the percentage of relative humidity detected at the operator station.



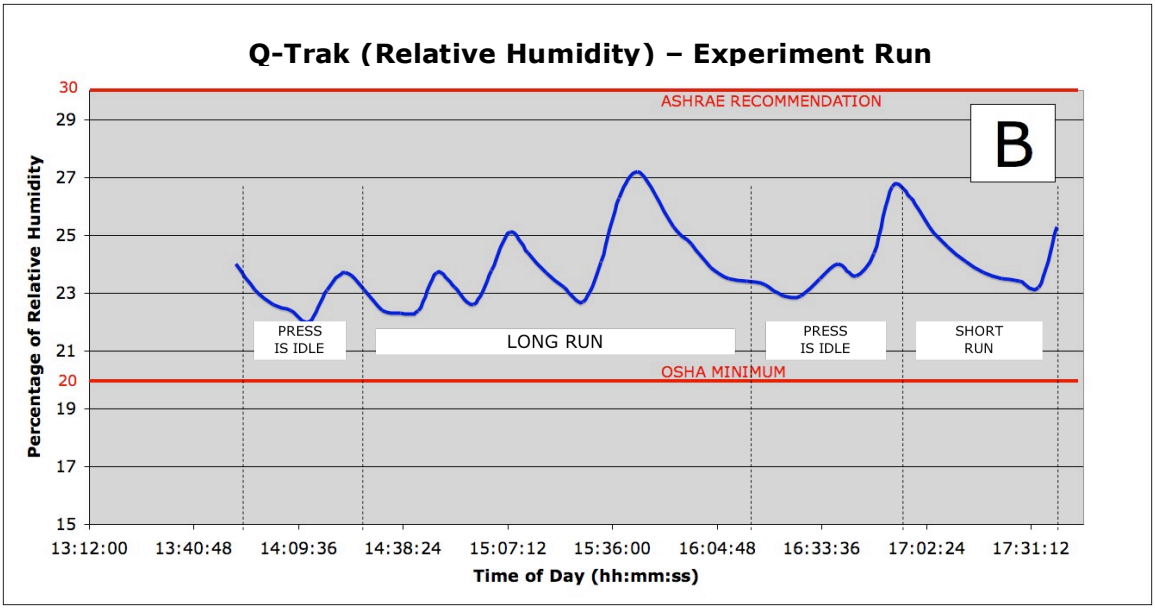


Figure 14: Relative Humidity During the Preliminary (A) and Experiment (B) Runs

One of OSHA's general rules is that office (indoor) temperature and relative humidity are matters of human comfort rather than hazards that could cause death or serious physical harm. OSHA has no specific regulations addressing them; however, Section III, Chapter 2, Subsection V of the OSHA Technical Manual, "Recommendations for the Employer," provides the following guidance to prevent or minimize indoor air quality issues: temperature must be in the range of 68-76 °F and relative humidity in the range of 20-60%. In its Standard 55, "Thermal Environmental Conditions for Human Occupancy," ASHRAE recommends 68-74 °F during the winter and 30-60% relative humidity as conditions that will be acceptable to 80% or more of the occupants within the space.

Relative humidity is important for most print-on-paper processes because low percentages are catalysts for static electricity sparks, which are hazardous to electronic components inside printers, and they can cause the paper sheets to electrostatically adhere together, which results in paper jams –especially during the winter, when outdoor air becomes dryer. On the other hand, high percentages of relative humidity cause paper to absorb moisture and deform, resulting in paper jams inside the machine.

As seen in Figure 14A, the relative humidity recorded during the preliminary run was below the OSHA recommended minimum of 20%, going as low as 18.6%. These levels are also below the ASHRAE minimum of 30%. The experiment run was within the OSHA recommendation, but still below the ASHRAE minimum of 30% (see Figure 14B). Therefore, if static electricity discharges become frequent inside the room, the moisture in the air can be increased using industrial air humidifiers.

Figure 15 shows the temperature recorded at the operator station by the Q-Trak.

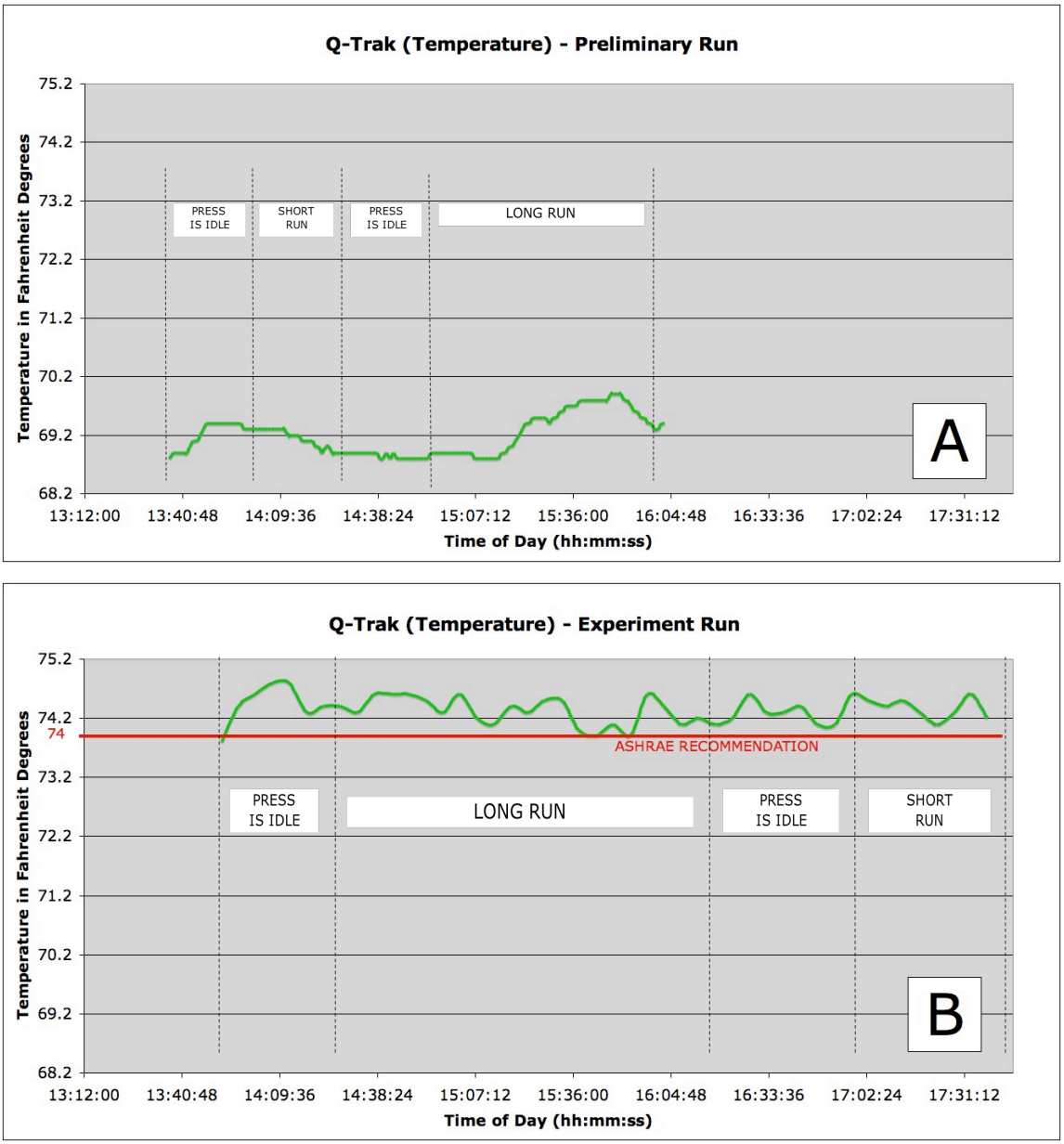


Figure 15: Temperature During Preliminary (A) and Experiment (B) Runs

The temperature recorded in all instances was in accordance with OSHA; it never went below 68 °F or above 76 °F. However, it exceeded the ASHRAE maximum of 74 °F during most of the experiment run (see Figure 15B). There was a 4 °F difference between the temperature at the operator station of the small room and that of the Demo room, and it was assigned to the ventilation systems of these rooms, which were located at different buildings of the Kodak Manitou facility. If the operator manifests discomfort with the slightly elevated temperature in the Demo room, the temperature can be decreased by the air-conditioning system.

Respirable Dust, Ultrafine Particulates, and Total Dust

Figure 16 shows respirable dust concentrations detected by the DustTrak.

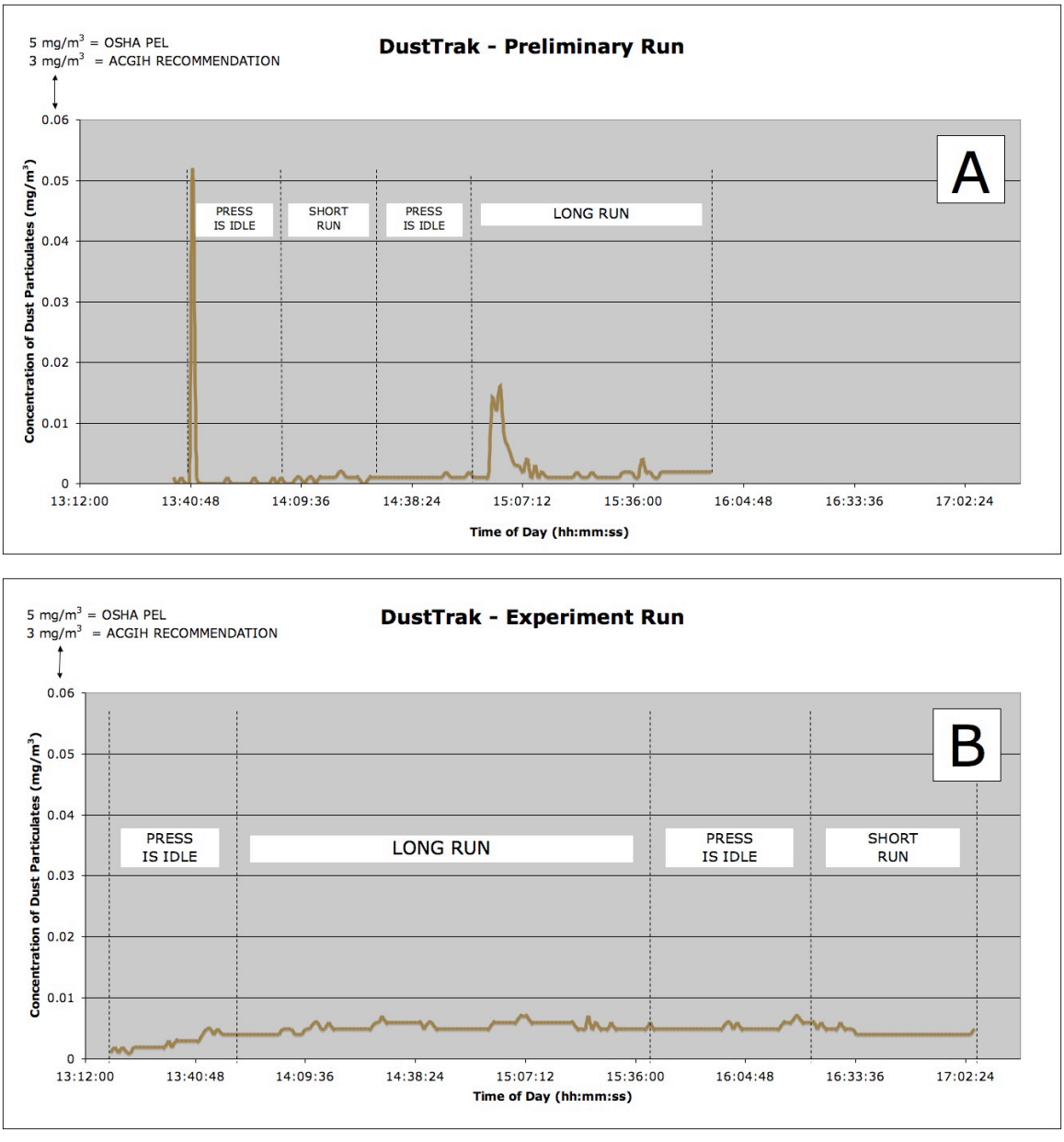


Figure 16: Respirable Dust Concentrations Detected During the Preliminary (A) and Experiment (B) Runs

The American Conference of Governmental Industrial Hygienists (ACGIH) is an independent organization that advances occupational and environmental health; ACGIH is to respirable dust what ASHRAE is to ventilation. ACGIH recommends a maximum respirable dust concentration of three mg/m^3 (ACGIH, 2000), which is well above any observed level.

Neither the first nor the second spike in Figure 16A, nor any measurement seen in Figure 16B, exceeded the OSHA PEL of five mg/m^3, according to Table Z-1 of Standard 29CFR1910.1000. In fact, even the 0.052 mg/m^3 spike (the first spike in Figure 16A) is 96 times smaller than the OSHA PEL. This spike has been deemed an unexplained anomaly. The reader may recall from the Methodology section that the order of the short and long print runs was inverted in the preliminary and experiment runs; one of the reasons for this change was to see if this particular spike was somehow associated with the long print run. However, the event did not repeat itself during the experiment run; therefore, this event has been dismissed as an anomaly. Another factor that suggested an anomaly is that this data point was neither preceded nor followed by a similar concentration level. This data point stands alone in the middle of an otherwise consistent curve.

The second spike in Figure 16A occurred approximately one hour and twenty minutes into the preliminary run and corresponds to the moment when the DustTrak was tested by spraying its air intake with compressed air, the type used to clean computers. This stirred the air around the intake and caused a sharp increase in the concentration of particulates smaller than 2.5 micrometers.

The unexplained anomaly is different from the second spike in that the former disappears as fast as it appeared, whereas the latter decreases slowly, as expected from an event that is not an anomaly. The small spikes (or cycles) seen in both graphs are within the resolution of this instrument (± 0.001 mg/m^3). Nothing in the recorded data indicates that (under normal operating conditions) the NexPress 2500 has any impact in the concentration of respirable dust particulates smaller than 2.5 micrometers.

Figure 17 shows the ultrafine particulate concentrations detected by the P-Trak.

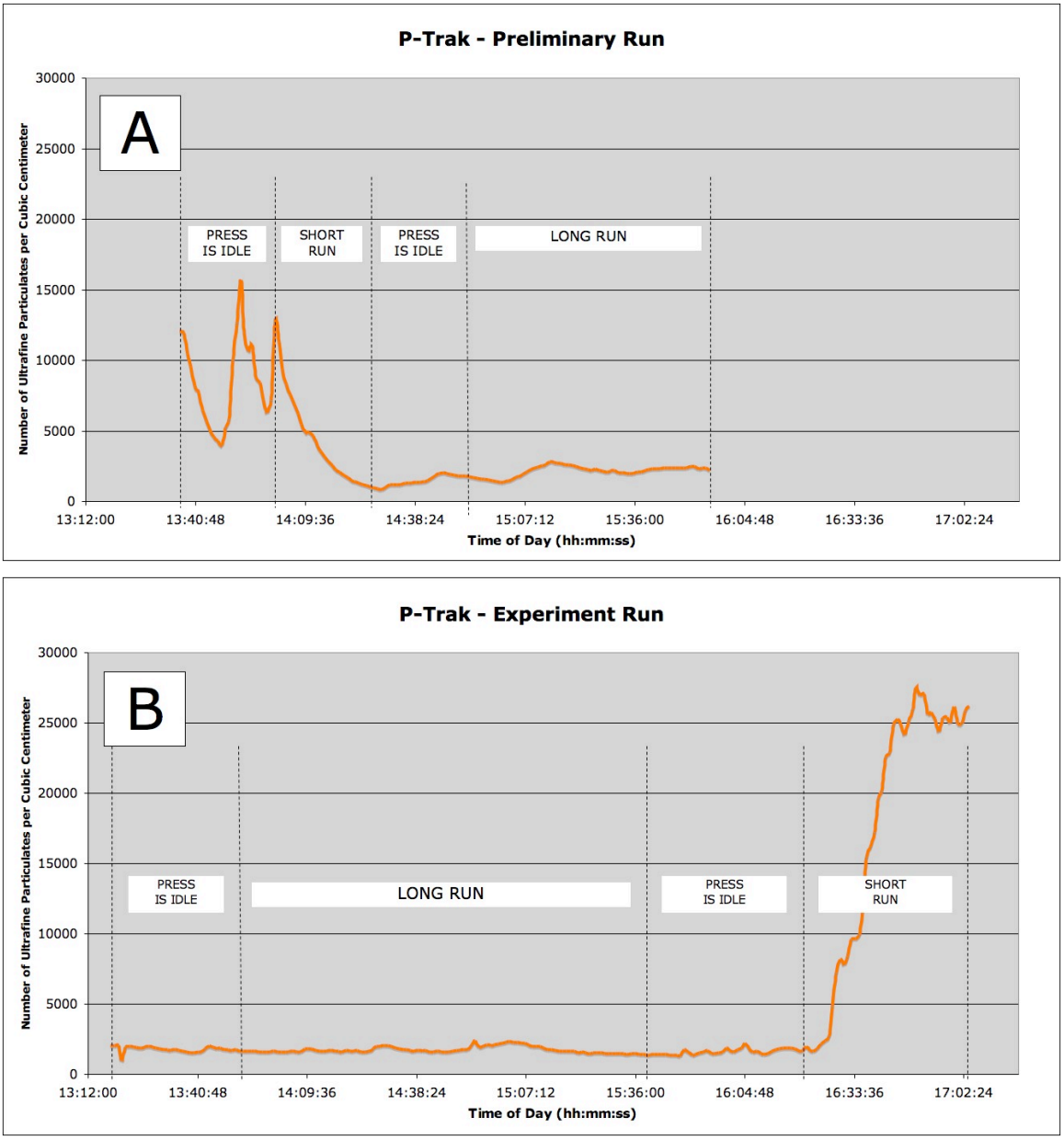
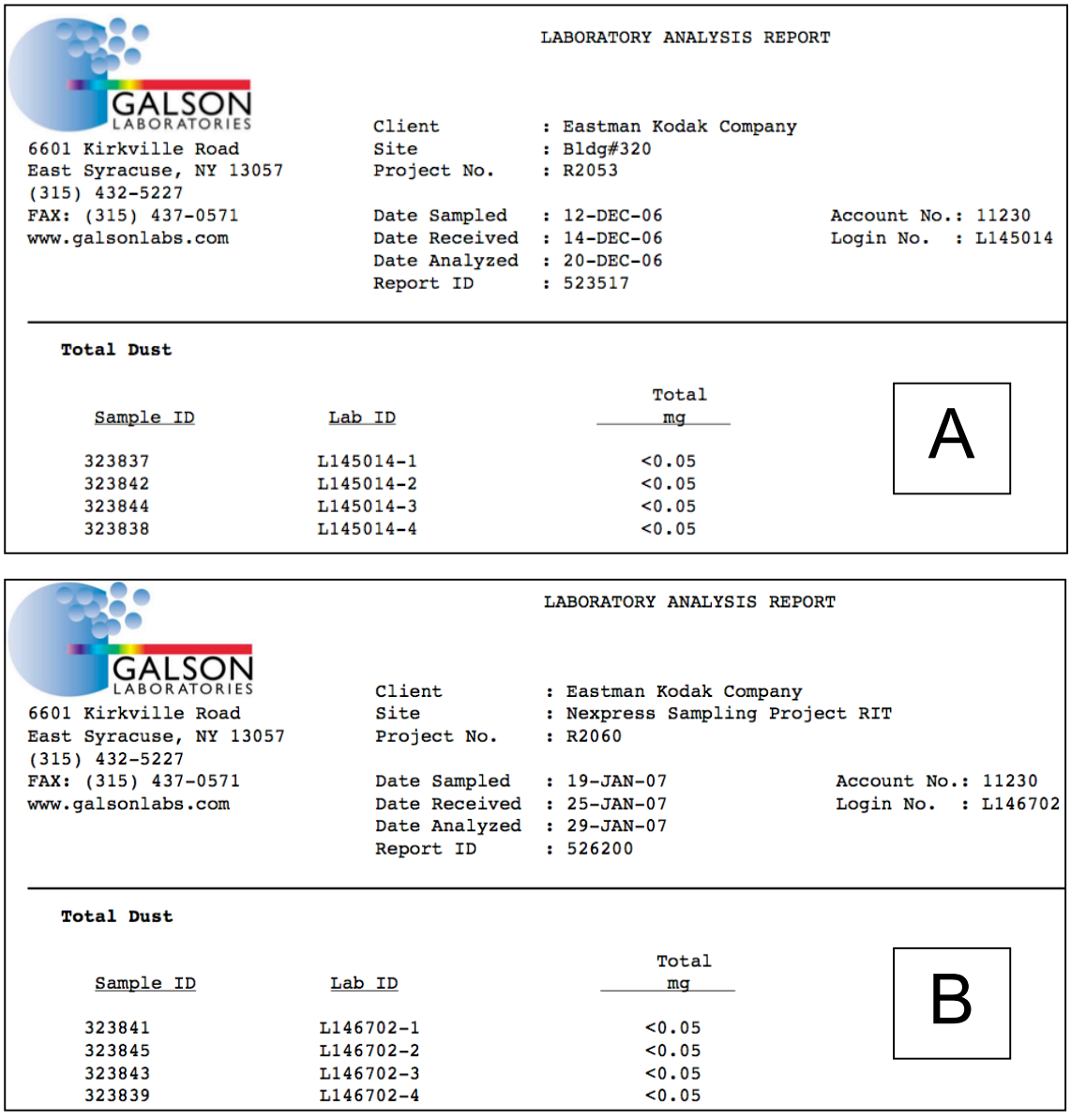


Figure 17: Ultrafine Particulates During the Preliminary (A) and Experiment (B) Runs

The spikes at the start of Figure 17A occurred at the same time the NexPress 2500 was turned on, performed a self check, and underwent a calibration cycle. Ultrafine particulates may be sitting on top, inside of and around the press; as the press is turned on, its fans and vibration may displace the ultrafines. The sharp rise in ultrafine particulate levels at the end of Figure 17B is tied to the operation of the nearby Kodak Digimaster 9110 Digital Production System; the ultrafine count rose precisely when the Digimaster started running. A second reason for this sharp rise at the end of Figure 17B is that during the long run, the printed sheets were discharged to the main delivery unit, located inside the machine behind a closed door. During the short run, in contrast, the operator had them discharged to the proof tray, where they were exposed to the room atmosphere (see the top left of Figure 3). This allowed more ultrafines to reach the P-Trak during the short run.

Finally, gravimetric determination of particulate matter was used to calculate total dust. The cellulose filters used in this method only retain particulates larger than five micrometers in diameter.

Galson Laboratories conducted the mass measurements seen in Figure 18. The most important fact is that the laboratory reports "less than" milligram values, rather than total milligram values. This is because 0.05 milligrams is the resolution of the instruments used by Galson Laboratories.



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LABORATORY ANALYSIS REPORT

Client : Eastman Kodak Company
Site : Bldg#320
Project No. : R2053

Date Sampled : 12-DEC-06
Date Received : 14-DEC-06
Date Analyzed : 20-DEC-06
Report ID : 523517

Account No.: 11230
Login No. : L145014

Total Dust

Sample ID	Lab ID	Total mg
323837	L145014-1	<0.05
323842	L145014-2	<0.05
323844	L145014-3	<0.05
323838	L145014-4	<0.05

A

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LABORATORY ANALYSIS REPORT

Client : Eastman Kodak Company
Site : Nexpress Sampling Project RIT
Project No. : R2060

Date Sampled : 19-JAN-07
Date Received : 25-JAN-07
Date Analyzed : 29-JAN-07
Report ID : 526200

Account No.: 11230
Login No. : L146702

Total Dust

Sample ID	Lab ID	Total mg
323841	L146702-1	<0.05
323845	L146702-2	<0.05
323843	L146702-3	<0.05
323839	L146702-4	<0.05

B

Figure 18: Laboratory Analysis Reports for Milligrams of Total Dust Collected During the Preliminary (A) and Experiment (B) Runs

The author divided these (less than) milligram values by the volume of the room (in cubic meters) in which each print run (A and B) took place. Figure 19 shows how this calculation was done.

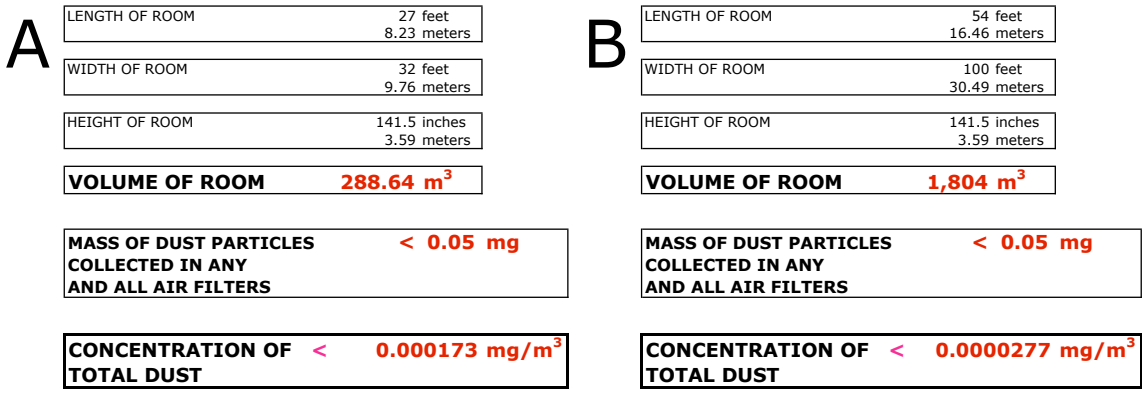
A
LENGTH OF ROOM 27 feet 8.23 meters
WIDTH OF ROOM 32 feet 9.76 meters
HEIGHT OF ROOM 141.5 inches 3.59 meters
VOLUME OF ROOM 288.64 m3
MASS OF DUST PARTICLES COLLECTED IN ANY AND ALL AIR FILTERS < 0.05 mg
CONCENTRATION OF TOTAL DUST < 0.000173 mg/m3
B
LENGTH OF ROOM 54 feet 16.46 meters
WIDTH OF ROOM 100 feet 30.49 meters
HEIGHT OF ROOM 141.5 inches 3.59 meters
VOLUME OF ROOM 1,804 m3
MASS OF DUST PARTICLES COLLECTED IN ANY AND ALL AIR FILTERS < 0.05 mg
CONCENTRATION OF TOTAL DUST < 0.0000277 mg/m3

Figure 19: Calculation of the Concentration of Total Dust During the Preliminary (A) and Experiment (B) Runs

As seen in Figure 18, the four filters analyzed for either run by Galson Laboratories had a mass of "less than" 0.05 milligrams (mg). Dividing this number by the volume of the room (calculated in Figure 19) gives a concentration of less than 0.000173 mg/m^3 in the case of the preliminary run, and less than 0.0000277 mg/m^3 during the experiment run in the much larger Demo room. Both concentrations are far below the OSHA PEL of 15 mg/m^3 (according to Table Z-1 of Standard 29CFR1910.1000), as well as below the ACGIH recommended maximum of 10 mg/m^3 (ACGIH, 2000).

Volatile Organic Compounds

Figure 20 shows volatile organic compound levels detected by the TVA-1000.

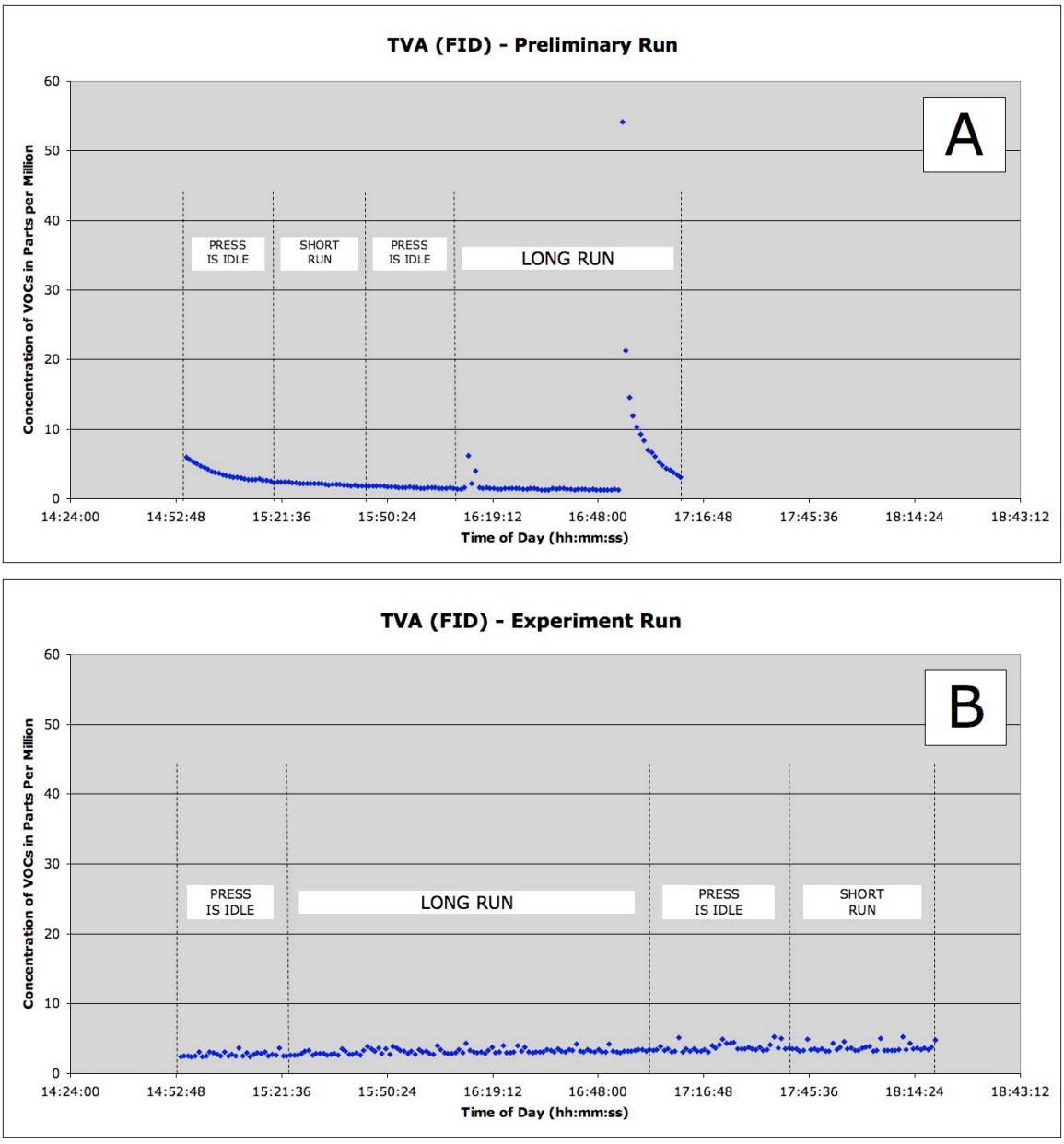

Figure 20: VOC Emissions During the Preliminary (A) and Experiment (B) Runs

The spike in Figure 20A corresponds to the author's computer-cleaning aerosol experiment as described in the respirable dust section, and it was triggered by a hydrocarbon called tetrafluoroethane. No significant levels of VOCs above background were detected during either of the runs of the NexPress 2500 other than the spike in Figure 20A. What Figure 20B shows may be the instrument's zero base-lined drift. According to Technical Service of the Foxboro Company (the manufacturer of the TVA-1000B), this instrument is susceptible to this phenomenon, which involves the resistance in the (Wheatstone bridge type) metering circuits inside this instrument. As mentioned previously, when the Flame Ionization Detector of the instrument works, the hydrocarbons in the sample gas react with the hydrogen flame and release ions, while a collector electrode with a polarizing voltage attracts these ions. The migration of these ions produces a current, which is directly proportional to the concentration of hydrocarbons introduced to the flame. This current is then amplified and sent to a microprocessor and an analog readout device.

It is during this last step that the zero drift occurs: some of the electrons in this current bounce back (a form of feedback), and the instrument interprets these electrons collectively as very low levels of hydrocarbons, which are seen in Figure 20B. The only way to control this phenomenon is to calibrate the instrument constantly (J. Schneider, personal communication, 2007). This effect is most visible when the instrument is trying to measure levels close to zero because the instrument hovers over a range where it is hard to distinguish current from non-current.

Ozone Emissions

Figure 21 shows ozone levels detected by the Ozone Analyzer.

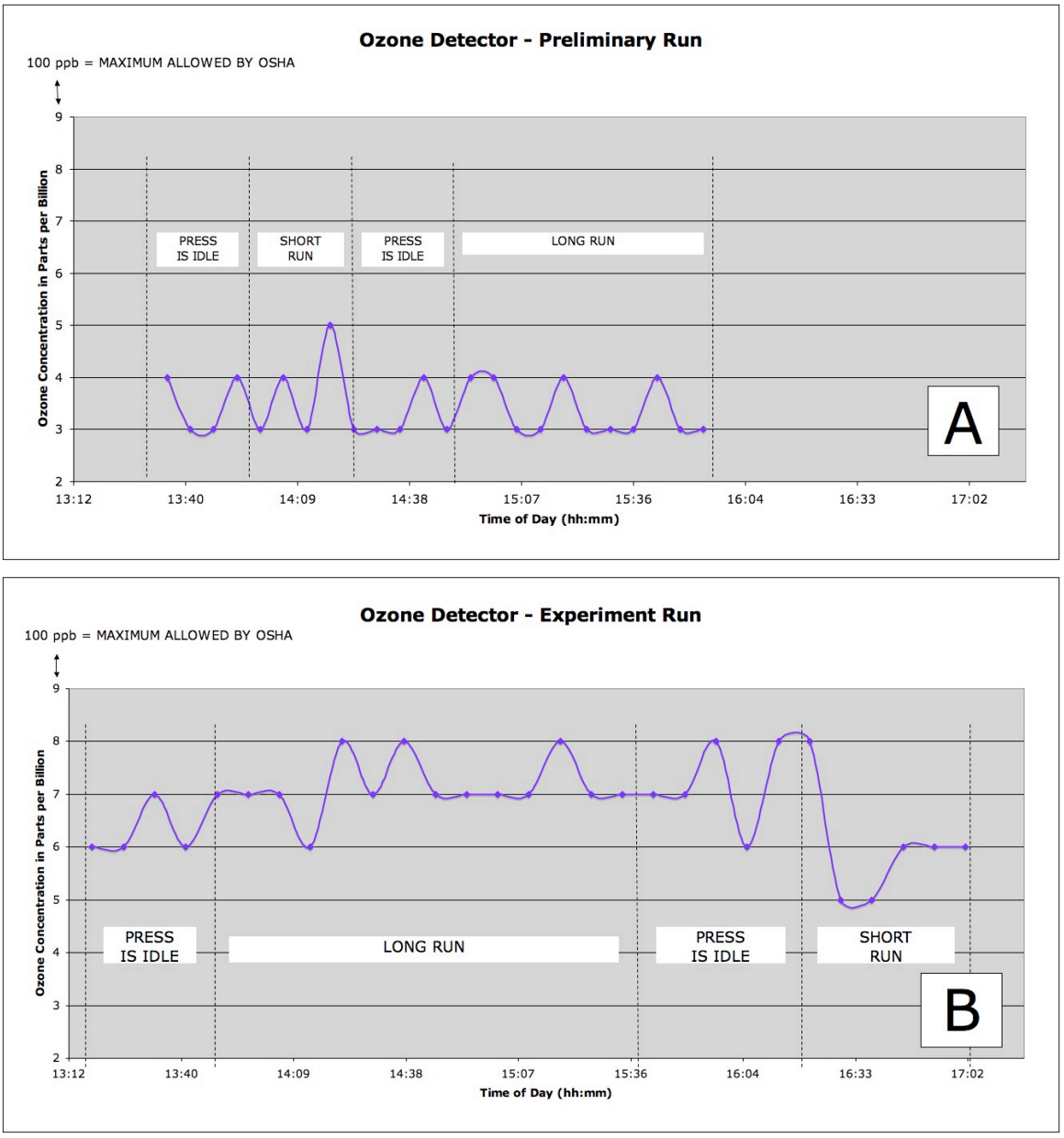

Figure 21: Ozone Levels Recorded During the Preliminary (A) and Experiment (B) Runs

As seen in Figure 21, ozone experiment run levels (Figure 21B) double those of the preliminary run (Figure 21A). This can be attributed to the fact that during the experiment run, there were other digital printing machines running in the Demo room, such as the aforementioned Digimaster. Ozone may be formed from oxygen by electrical discharges and by action of high-energy electromagnetic radiation. This is especially true in devices that use high voltages, such as the paper cutter, the glosser, the Digimaster, and also the NexPress. The relative position of these machines can be seen in Figure 22.

The apparent cycles in Figure 21A and B are within the resolution of the photometric analyzer, which is ± 0.001 ppm, or ± 1 ppb. For example, if the amount of ozone in the air is exactly 3.5 ppb, the readings from the instrument will oscillate between 3 and 4 ppb, as they do in Figure 21A. In fact, the ozone concentration did not rise or fall, but because the instrument's resolution is 1 ppb and not 0.5 ppb or less, the instrument will not be able to detect that constant 3.5 ppb level but will oscillate above and below it.

The PEL for ozone in the workplace is 100 ppb, according to Table Z-1 of the OSHA Standard 29CFR1910.1000, which is identical to the ACGIH TLV for light work. The highest ozone concentration detected during the runs was 8 ppb, less than a tenth of the OSHA PEL. Background ozone levels reached on average 4 ppb, and when the NexPress was running, the ozone level never rose beyond 8 ppb. Therefore, the worst case scenario (i.e., if we ignore all the other ozone-emitting devices in the Demo room) was that the NexPress, at its peak of ozone generation, emitted that 4 ppb difference. The instrument probe was inserted in the machine after the experiment run was complete, and

a concentration of 39 ppb was detected. Assuming that the 4 ppb of ozone somehow eluded the factory-installed NexPress 2500 filters, these filters were 89% (= 35/39 ppb) efficient, and the ozone that eluded them was still 4% of the PEL. Figure 22 is a not-to-scale sketch of the Demo room on the day the experiment run was executed.

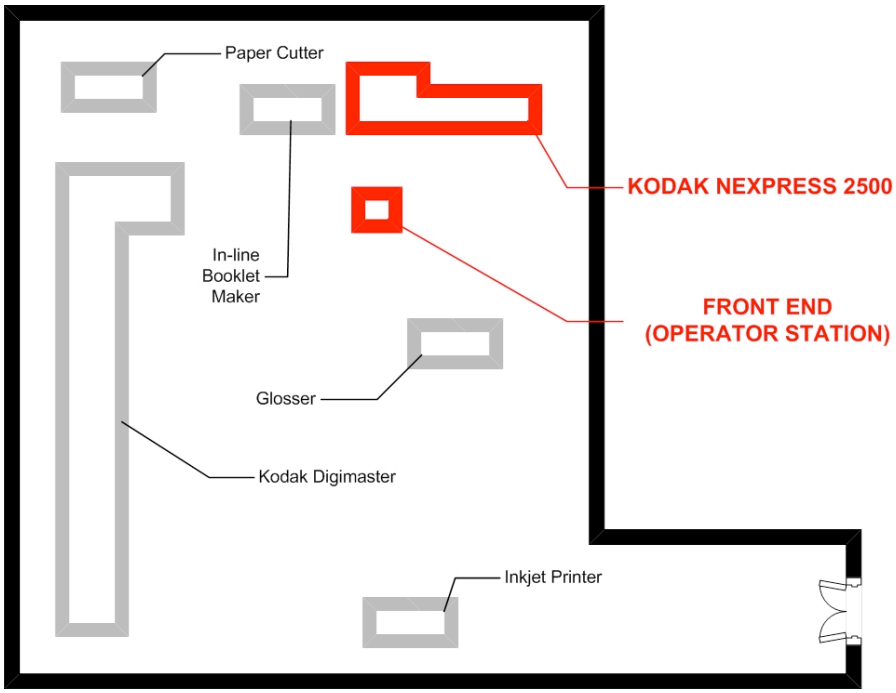

Figure 22: Sketch of Kodak's Manitou Demo Room

Figure 22 shows how other digital printing devices and peripheral machines were distributed around the NexPress. Operating any of these electrical devices will raise the ozone levels in the room, just as it occurred during the experiment run (Figure 21B) when compared to the preliminary run (Figure 21A).

Noise Levels

Average noise levels detected by the four stationary dosimeters are shown in Figure 23.

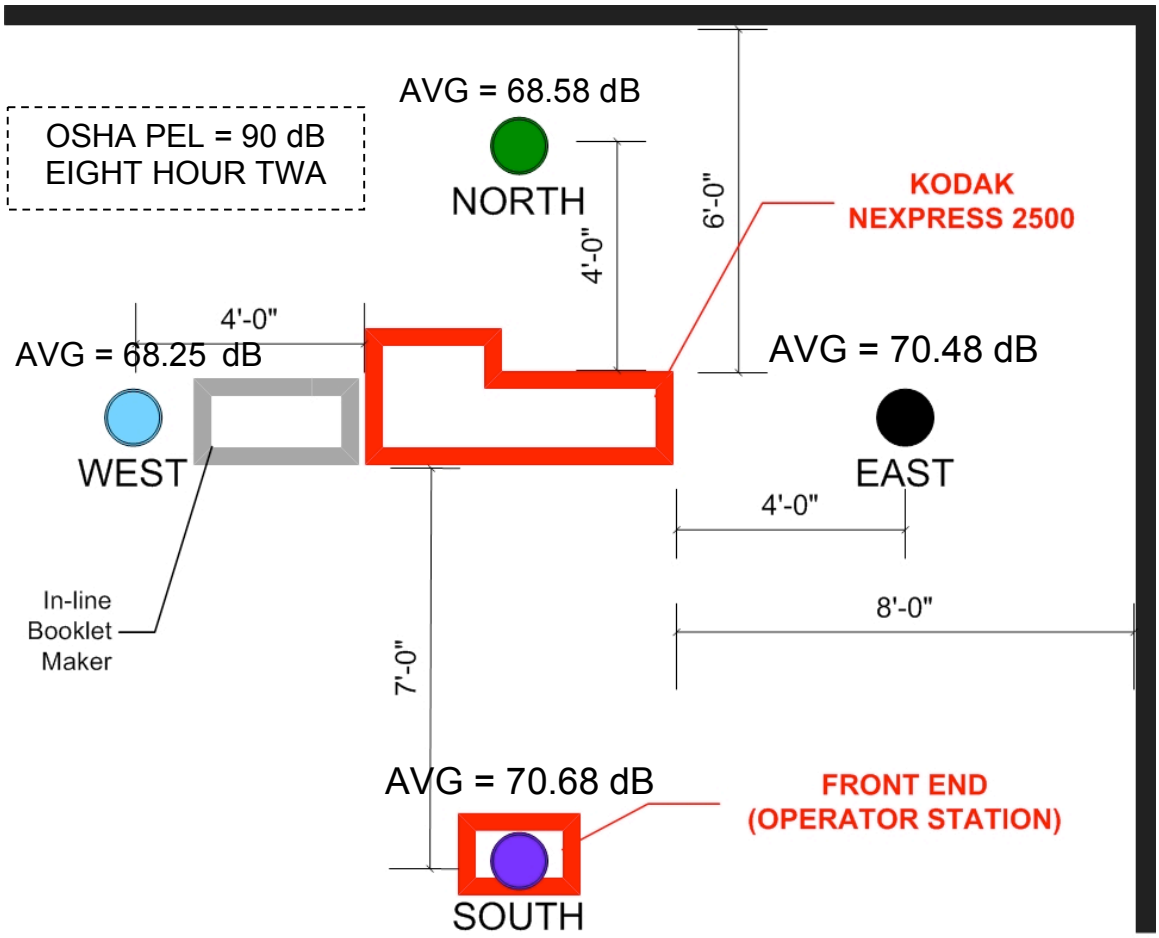

Figure 23: Not-to-scale Sketch of the Distribution of the Stationary Noise Dosimeters

The noise level samples taken during the experiment run are representative of those that occur during any given continuous eight-hour workday. Kodak scientists and NexPress operators validated this crucial assumption, which allows comparison of

average noise values measured with the OSHA PEL of 90 dB as time-weighted average (TWA) of eight hours. This TWA PEL, as well as the peak noise PEL of 140 dB, appears in OSHA Standard 29CFR1910.95.

The operator was, on average, exposed to the highest levels of noise: 71.97 dB. The dosimeter located west of the NexPress was exposed to the least amount of noise: 68.25 dB. Figure 24 shows the noise levels recorded by all the dosimeters.

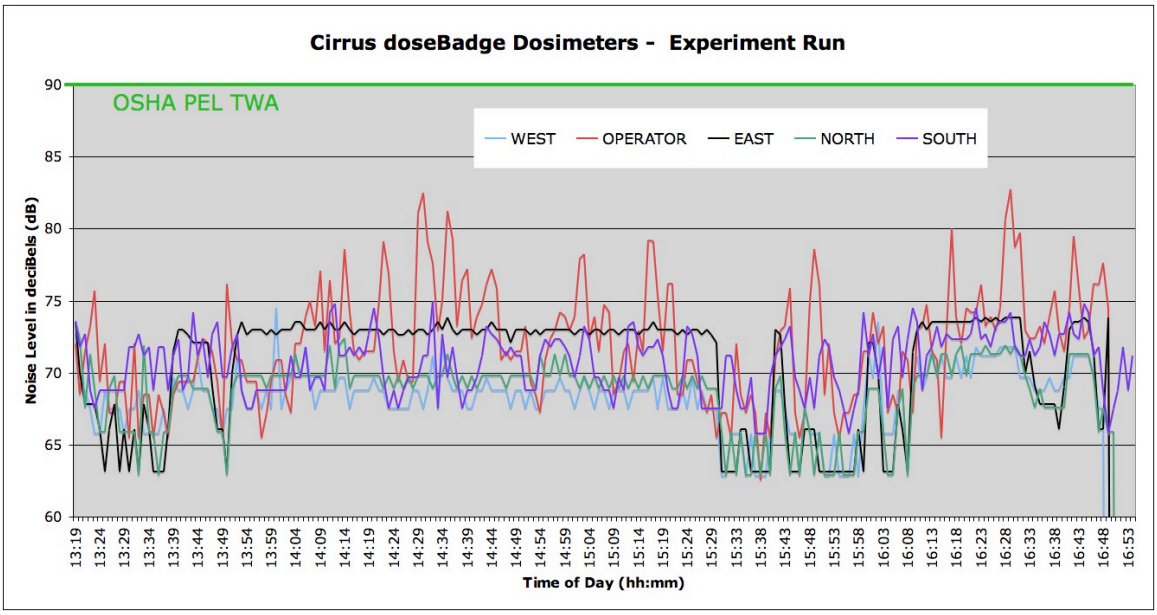

Figure 24: Noise Levels Detected by All Five Dosimeters Around the NexPress

The red curve in Figure 24 corresponds to the dosimeter that was carried by the operator, and by comparison to the other four curves, it is evident that the operator was exposed to higher decibel levels than any of the other dosimeters. Each curve is analyzed separately in the following pages.

Figure 25 shows the noise levels that the operator sustained.

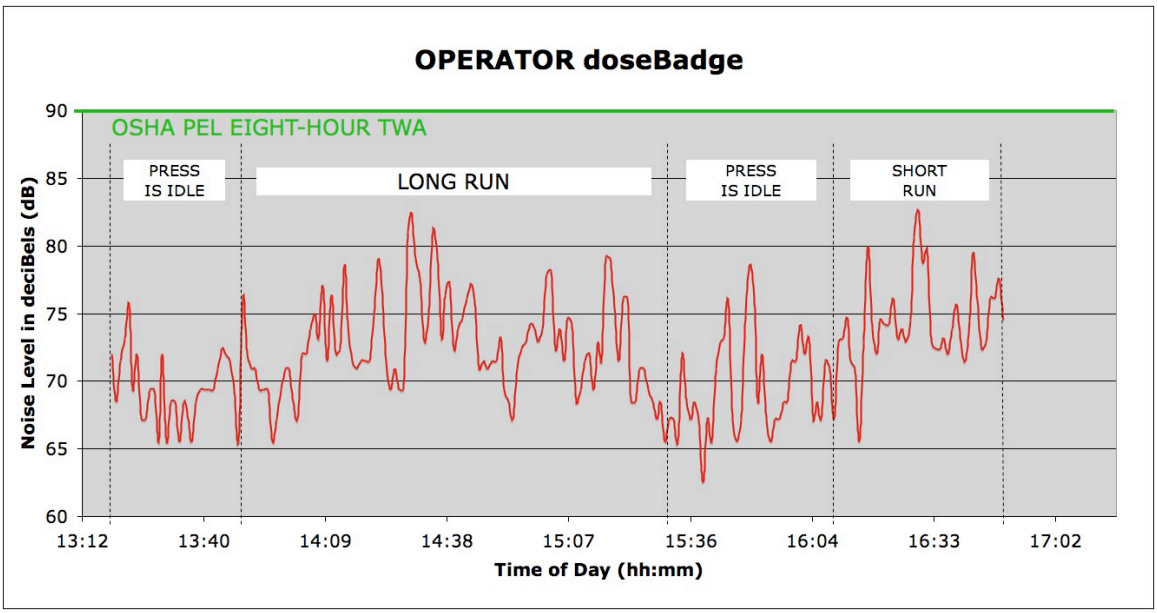

Figure 25: NexPress Operator's Noise Exposure Levels During the Experiment Run

In Figure 25 there are three distinct moments –two at the middle of the long run (82.5 dB and 81.2 dB), and one in the middle of the short run (82.7 dB, the noise peak of the experiment)– when the noise level rose above 80 dB. The numerous smaller spikes in the curve correspond to moments when the operator came closer to the machine, raised his voice, and/or held conversations with the other people in the Demo room. The noise level went below 65 dB when the NexPress was stopped after the long run and was made ready for the short run. In average, the operator was exposed to 71.97 dB of noise.

Figure 26 shows the noise levels at the operator station, seven feet south of the NexPress.

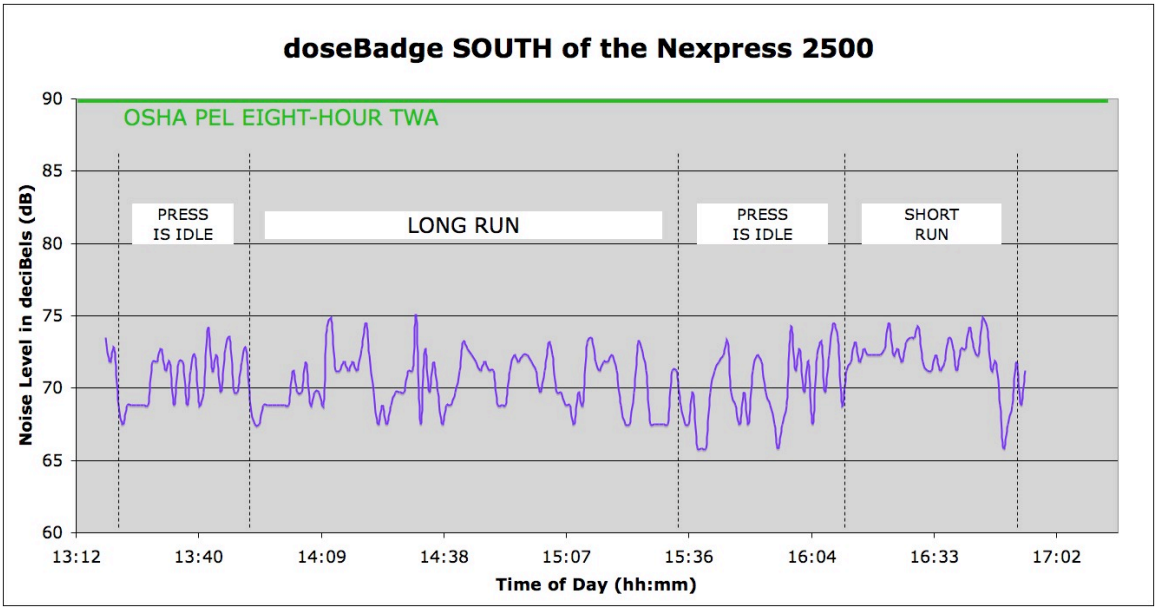

Figure 26: Noise Levels Detected at the Operator Station During the Experiment Run

Sound levels never exceeded 75 dB at the operator station and never went below 66 dB. This dosimeter did not detect any significant differences in noise levels between the short and long run. However, it detected, in average, a relatively high noise level of 70.68 dB (the second highest) despite the fact that it was the farthest away from the NexPress.

Figure 27 shows the noise levels east of the machine, halfway between the NexPress and one of the walls.

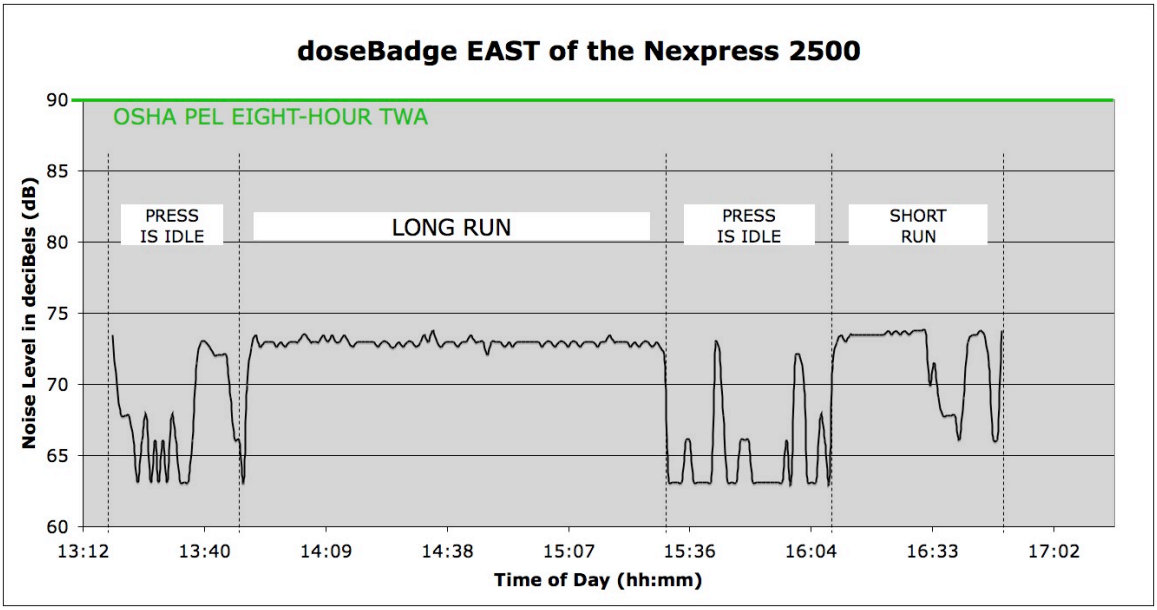

Figure 27: Noise Levels Detected East of the Press

Out of the five dosimeters, the east dosimeter most clearly reflects the time periods that correspond to the long print run, followed by a pause, followed by the short print run. As with all the other stationary dosimeters, the east dosimeter never picked up noise levels above 75 dB. This dosimeter detected, in average, a noise level of 70.48 dB.

Figure 28 shows the noise levels north of the NexPress.

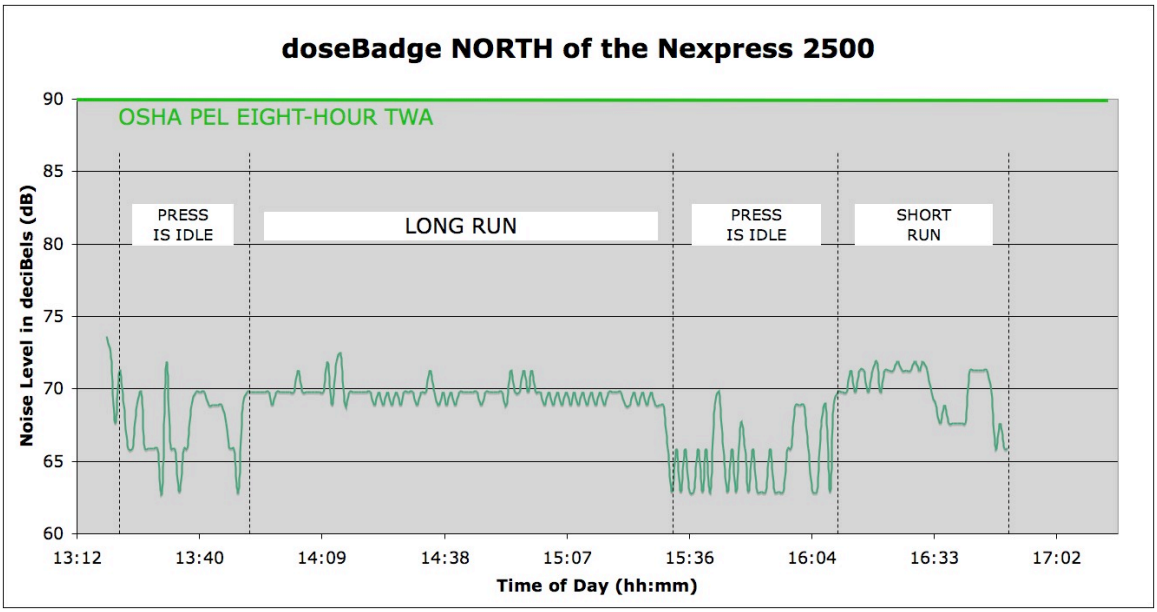

Figure 28: Noise Levels Detected North of the Press

The north dosimeter also shows a dip in noise levels just before the long run, and before the short run, which correspond to machine idle cycles. This particular dosimeter was more tightly "squeezed" between the NexPress and the back wall, and one would have expected sound waves to bounce back from the wall and elevate noise levels above those picked up by the other dosimeters, but that was not the case. This dosimeter detected, in average, a noise level of 68.58 dB.

Figure 29 shows the noise levels West of the NexPress.

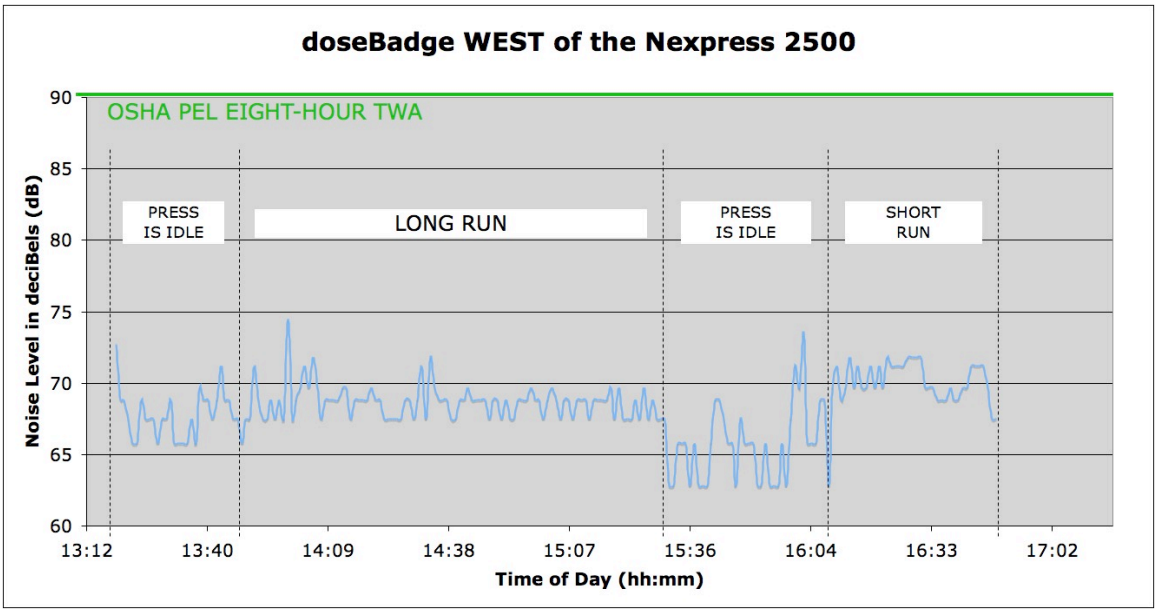

Figure 29: Noise Levels Detected West of the Press

Even though this dosimeter was located west at the same distance from the NexPress as the east dosimeter, the former picked up all-around lower noise levels than the latter. This could be due to the fact that the west dosimeter was not "sandwiched" between a wall and the press, as was the east dosimeter. This dosimeter, like the north dosimeter, was able to distinguish the moments when the press was idle between the long and short run. This dosimeter detected, in average, a noise level of 68.25 dB.

Evaluation of the Hypotheses and Comparison to the Kadam Results

The author set out to prove or disprove the following three hypotheses, which are the overlapping points of the Kadam study and the present study:

1. ***H_o1***: VOC emissions are higher in liquid ink digital printing and sheetfed offset lithography when they are compared separately to dry toner digital printing VOC emissions, both in short and long runs. Outcome: No significant VOC emissions were associated with the operation of the NexPress 2500 in all instances; Kadam detected as much as 30 ppm of VOCs. Therefore ***H_o1 is true.***

2. ***H_o2:*** Respirable dust level emissions are higher in liquid ink digital printing and sheetfed offset lithography when they are compared separately to dry toner digital printing respirable dust emissions, both in short and long runs. Outcome: Kadam detected concentrations just under 0.3 mg/m^3 in both processes, whereas operation of the NexPress 2500 was associated with respirable dust levels of less than 0.052 mg/m^3 in all instances. Therefore ***H_o2 is true.***

3. ***H_o3:*** Eight-hour, time-weighed average noise levels are higher in liquid ink digital printing when they are compared to dry toner digital printing levels, in both runs. Outcome: Kadam recorded an average of 61.9 dB in digital printing, whereas the current study recorded 77.58 dB. Therefore ***H_o3 is false.***

Table 6 summarizes the results of the present study compared to the results of the Kadam study. In the cases where there are two limits, such as the case of total dust, for which OHSA mandates a maximum of 15 mg/m^3 and ACGIH suggests no more than 10 mg/m^3, the lower (safer) of the two limits is shown on Table 6.

Table 6: Comparison of Results of the Kadam Study and the Present Study

EHS Aspect	PEL or TLV	Kadam Lithography	Kadam Wet Ink	Leal Dry Toner
Respirable Dust Concentrations	3 mg/m^3	< 0.3 mg/m^3	< 0.3 mg/m^3	< 0.052 mg/m^3
Ultrafine Concentrations	None	–	–	< 30,000 pt/cm^3
Total Dust Concentrations	10 mg/m^3	< 0.8 mg/m^3	< 0.9 mg/m^3	< 0.000173 mg/m^3
VOC Concentrations	100 ppm	30 ppm	18.5 ppm	< 6 ppm
Ozone Concentrations	100 ppb	–	–	< 8 ppb
Peak Noise Levels	140 dB	147.7 dB	120.6 dB	82.7 dB
8-Hour TWA Noise Levels	85 dB	63.1 dB	61.9 dB	77.6 dB

The respirable and total dust levels in Table 6 show that the NexPress 2500 emits fewer dust particulates than either the Heidelberg Speedmaster 74 or the HP Indigo 3000. However, this conclusion may prove to be false. Kadam makes no mention of the volume of the rooms, nor of the environmental conditioning systems present in the rooms in which his measurements took place. It may well be that the three machines emit the same mass of dust particulates, but if the Demo room is much larger than the others, the dust concentrations from the NexPress will be lower. Only under the assumption that the three

rooms had identical volume can it be concluded that the NexPress 2500 emits less respirable dust (and less total dust) than the Heidelberg Speedmaster 74, or the HP Indigo 3000.

In the case of VOCs, the author knows by having examined the MSDS for the NexPress consumables that there should not be any VOCs emitted by the NexPress. The "less than 6 ppm" is considered a background level. Essentially, what the instrument indicates is that there are no significant levels of VOCs being emitted by the NexPress.

The peak noise level detected in the lithographic process exceeded the OSHA PEL; however, the exposure was momentary (not sustained) and unfortunately Kadam does not explain it nor theorize. Noise peaks in both wet and dry digital printing were below permitted levels, with dry toner digital printing proving to be the safer technology.

Time-weighted average noise levels were higher in dry toner digital printing than in lithography or wet ink printing. This can be explained by the fact that the author used five different dosimeters, deliberately distributed four feet around the printer, and one carried by the operator, whereas Kadam only used one noise level meter attached to the operator.

Based only on these four parameters (respirable dust, total dust, volatile organic compound emissions, and noise peak levels), it can be concluded that the environmental footprint of the NexPress 2500 is smaller than that of the Heidelberg Speedmaster 74 and the HP Indigo 3000.

Chapter 7

Conclusions

Summary

The experiments conducted on two different Kodak NexPress 2500 digital production color presses yielded favorable air quality and noise level results on all aspects under observation.

Carbon dioxide levels during normal operation of the NexPress 2500 reached concentrations that are a mere 11% of OSHA permissible exposure levels and 47% of the ASHRAE recommended maximum. There was no evidence to suggest that the operation of the NexPress had any effect on the CO_2 concentration levels. A second conclusion is that both rooms where the NexPress 2500s have been installed are adequately ventilated, since it is generally understood that elevated CO_2 levels are an indicator that an indoor environment is poorly ventilated.

Relative humidity and temperature at the operator station are within the Nexpress operating parameters, although relative humidity was low in the room where the preliminary run was conducted. If the operator manifests no discomfort, and the press performs flawlessly, then there is no need to install industrial air humidifiers in the room.

Relative humidity has an impact on operator comfort, is a potential cause of paper jams, and has to be within a specific range for the NexPress to operate properly. In addition, if too high, relative humidity can facilitate the growth of dust mites and molds (ASHRAE, 2007). Kodak has equipped the NexPress with an Environmental Control System that exerts negative pressure to the air outside the machine and conditions it to optimal operating levels throughout the printing cycle (inside the press). The results indicated that the normal operation of the NexPress has no impact on temperature or relative humidity levels of its surroundings.

Respirable dust levels were found in very low concentrations at the operator's breathing zone –the average being 500 times lower than the OSHA PEL, and 300 times lower than the ACGIH maximum. The concentration of respirable dust before, during, and after the NexPress was operated did not change significantly. This means that the NexPress Contamination Control subassembly was successfully removing waste dry toner and other environmental contaminants from the printing process; therefore, the NexPress does not add significantly to air pollution at the scale of 2.5 micrometers in diameter, the scale that corresponds to fine respirable dust.

There was evidence that the operation of the NexPress raises the concentration of ultrafine particulates in the operator's breathing zone, but then again, so does the operation of a nearby altogether different digital press, the Kodak Digimaster 9110. To put the recorded ultrafine levels into perspective, consider that the P-Trak detected 18,000 ultrafines per cubic centimeter in a carpeted office setting where 30 people work. This level means that (in comparison) the rooms in which the digital presses are located

are very clean rooms, registering most of the time less than 5,000 ultrafines per cubic centimeter. The ultrafine particulate results are inconclusive because, as of early 2007, there are no specific standards or guidelines have been developed specifically for ultrafine particulates. This is an area rich with potential for further research, and until this is done, it is not fair to say that the NexPress emits high, moderate, or low levels of ultrafine particulates, from 20 nanometers to 1,000 nanometers in diameter.

Neither the NexPress toner nor the developer can account for the concentrations of respirable dust or ultrafine particulates. The reason was that the toners have a volume average diameter of eight micrometers, and developers (which consist of toner and carrier) have a carrier that has a volume average diameter of 15 micrometers. Therefore, it can be concluded that neither the NexPress toners nor the developers play any role in respirable dust or ultrafine particulate concentrations. This is not necessarily the case for total dust concentrations.

Gravimetric analysis revealed that the concentration of total dust in the rooms where the NexPress were installed were five orders of magnitude lower than OSHA PEL and ACGIH recommendation during the preliminary run, and six orders of magnitude lower during the experiment run. This means that the factory-installed Contamination Control system filters much of the toner, developer, and paper debris that escape the printing process and does not allow it to go outside of the press.

Neither the NexPress 2500 nor its peripherals are a significant source of volatile organic compounds. This was expected because none of the Material Safety Data Sheets associated with the NexPress mention organic volatiles. In the NexPress, there are no

solvents involved in the process, and any fuser oil vapor is collected and vented though filters prior to being exhausted to the outside. In conclusion, under normal operating conditions, the NexPress operators will not exceed any recommended VOC exposure guideline.

As part of its Environmental Control System, the NexPress 2500 is equipped with activated-charcoal ozone filters that, according to the analysis of the recorded data, have an efficiency of 89% in the worst case (how this number was calculated is explained in the ozone Results subsection). The remaining ozone that was detected outside the press was only 4% of the EPA permissible exposure limit. This scenario, however, assumes that none of the other equipment (operating simultaneously in the same room as the NexPress) emits ozone. This is highly unlikely because these machines have similar ozone-generating components to those of the NexPress, such as electric motors. Therefore, the real ozone emission levels of the NexPress are lower than 4% of OSHA PEL. The difficulty lies in separating the ozone generated by the NexPress alone and the ozone generated by the other machines. In any case, the ozone filters are at least 89% efficient, and the operator was not at risk from even moderate exposure to this gas.

The sound level survey conducted around the NexPress revealed that the front of the press tends to be noisier than the back. The press has most of its access panels (doors) in the front, therefore, it was no surprise that most of the noise it generates inside bounces off the back and escapes the press through these panels in the front. Overall this was a quiet machine whose operation was not hazardous as far as noise was concerned. The

highest decibel levels detected, even had they been sustained during eight hours, did not exceed the time-weighted average (TWA) OSHA permissible exposure limit.

In Chapter 2 of this document (Applicable Mathematical Models), the cumulative noise detected by five dosimeters was calculated. The author used the five doseBadge averages obtained in the actual experiment run in that example, reaching an overall average of 77.58 dB for the NexPress. To put the 77.58 dB eight-hour average noise exposure in perspective, consider that operating a kitchen blender continuously at maximum speed during eight hours is considered hazardous because it meets the 90 dB eight-hour OSHA PEL. Operating a vacuum cleaner under the same conditions yields an 80 dB TWA exposure (wikipedia.org, 2007), which is acceptable. The noise level data supports the conclusion that noise levels (four feet and beyond) around the NexPress are well within OSHA and ACGIH requirements. This is a safe machine to operate without ear protection during eight continuous hours.

Perhaps the most important conclusion to be drawn by the analysis of the data was that there was no noticeable difference on any of the measured parameters between the short and the long runs. The recorded data suggest that this press was manufactured in such a way that its consumables are used up evenly, regardless of print count (the number of printed sheets). This may not be the case with power consumption, but this variable was not included in the present project and is grounds for further research.

Implications of the Findings

The results of this study indicate that the NexPress 2500 is safe to operate (only with regards to the EHS parameters herein tested) under normal conditions in the office environments in which they were studied. More specific implications include:

- Carbon Dioxide: assuming that the NexPress 2500 does not contribute to CO_2 emissions, and that its concentration can only be assigned to the exhalations of the people in the room at the time of the measurements, by extrapolation of the levels detected in this study, it would take ten persons at or around the operator station to meet the ACGIH limit, and 45 persons to exceed the OSHA PEL for CO_2.
- Respirable Dust: assuming that all the detected respirable dust concentrations can be assigned to the NexPress, the smallest room in which the press could be installed without exceeding the ACGIH TLV would have to be about five cubic meters, and exactly three cubic meters in order to exceed the OSHA PEL for respirable dust. None of these scenarios are possible because the press itself has a volume of 21 m^3.
- Total Dust: assuming that all the detected total dust concentrations can be assigned to the NexPress, the smallest room in which the press could be installed without exceeding the ACGIH TLV would have to be 0.005 cubic meters –smaller than a shoe box, and 0.003 cubic meters (about the size of a six pack of beer) in order to exceed the OSHA PEL for total dust.

- Volatile Organic Compounds: assuming that the 5.99 ppm of VOCs detected was not instrument noise, and further assuming that this VOC is the same that Kadam detected and for which the OSHA PEL is 100 ppm, it would take a room that is 17 m^3 (just under the volume of the press) to exceed this limit.
- Ozone: assuming that all the detected ozone concentrations can be assigned exclusively to the NexPress, the smallest room in which the press could be installed without exceeding OSHA and ACGIH limits would have to be 23 m^3, just over the actual size of the press, but still much too small.
- Noise: using the Calculation Method, and extrapolating the average noise emitted by one NexPress (77.6 dB as calculated by this study), it would take six presses installed in the Demo room to exceed the ACGIH limit, and 17 presses to exceed the OSHA PEL for eight-hour TWA noise exposure. All these presses would have to be four feet away from the operator station, which makes these scenarios unrealistic.

Agenda for Further Research

The author puts forth the following ideas for further research along the lines of the present study:

- Mass Balance Experiment: Time and budget constraints prevented the author from conducting such an investigation on the NexPress. It would be interesting to see if the NexPress measures up to its competitors on resource efficiency and waste generation levels.

- In-Depth Ultrafine Particulates Survey: Science is only beginning to understand the impact that ultrafine particulates have on human health. The author thinks that a full survey, involving numerous P-Trak devices located strategically around the press, is justified. In order to attempt to determine exactly what makes up these ultrafine particulates, this survey could be accompanied by chromatography.
- Power Consumption Analysis: This is important from cost optimization and environmental perspectives, and it will also help determine just how differently the NexPress 2500 handles short and long runs. In order to evaluate the energy requirements for short and long runs, all energy-consuming units such as press motors, hydraulic oil pumps, conveyor belts, fans, etc., have to be clearly identified and their power consumption measured. Energy efficiency metrics can be determined by relating total energy consumption to different print run lengths and/or usage of consumables.
- Ozone Emissions from Peripheral Equipment: The author suggests that the experiment be repeated on each of the other machines in the Demo room separately, with the rest of the machines turned completely off and their power supply cut. This should help determine exactly how much ozone each one emits independently and, thus, by subtraction, determine exactly how much is emitted by the NexPress 2500.

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